JOURNAL
OF THE
FISHERIES RESEARCH BOARD OF CANADA

Volume 17, No. 2

OHIO STATE UNIVERSITY
MAY 26 1960
LIBRARY

CONTENTS

PAGES

HART, J. L., AND D. L. MCKERNAN. International Passamaquoddy Fisheries Board Fisheries Investigations 1956–59. Introductory account 127–131

MCKENZIE, R. A., AND S. N. TIBBO. Herring fishery in southern New Brunswick 133–168

MARTIN, W. R. Predicted effects of proposed tidal power structures on groundfish catches in Charlotte County, N.B. 169–173

MCCRACKEN, F. D. Studies of haddock in the Passamaquoddy Bay region 175–180

BUMPUS, DEAN F. Sources of water contributed to the Bay of Fundy by surface circulation 181–197

PARKER, ROBERT R. Critical size and maximum yield for chinook salmon (*Oncorhynchus tshawytscha*) 199–210

OLSEN, STEINAR. Observations on sound scatterers in Newfoundland waters 211–219

NEAVE, FERRIS, AND M. G. HANAVAN. Seasonal distribution of some epipelagic fishes in the Gulf of Alaska region 221–233

LAMBERT, D. G. The food of the redfish *Sebastes marinus* (L.) in the Newfoundland area 235–243

(*Continued overleaf*)

OTTAWA
MARCH
1960

BATTLE, HELEN I., AND WILLIAM M. SPROULES. A description of the semi-buoyant eggs and early developmental stages of the goldeye, *Hiodon alosoides* (Rafinesque) 245–265

VLADYKOV, VADIM D. Description of young ammocoetes belonging to two species of lampreys: *Petromyzon marinus* and *Entosphenus lamottenii* 267–290

NOTES

Note on *Pontonema vacillatum* Leidy 1855 (Nematoda: Oncholaimidae) from soft-shell clams (*Mya arenaria*). By ROY C. ANDERSON AND NEIL BOURNE 291–293

Editor:

W. E. RICKER
Fisheries Research Board of Canada
P.O. Drawer 100
Nanaimo, B.C., Canada

Associate Editor:

N. M. CARTER
Fisheries Research Board of Canada
Ottawa, Ont., Canada

Manuscripts for publication should be addressed to the Editor

QUEEN'S PRINTER AND CONTROLLER OF STATIONERY
OTTAWA, 1960

International Passamaquoddy Fisheries Board Fisheries Investigations 1956–59 Introductory Account[1, 2]

By J. L. Hart

Fisheries Research Board of Canada
Chairman, Canadian Section, I.P.F.B.

and D. L. McKernan

Bureau of Commercial Fisheries
U.S. Fish and Wildlife Service
Chairman, U.S. Section, I.P.F.B.

In his search for sources of power to meet growing domestic and industrial needs man has always been intrigued by the thought of harnessing tidal forces. Nowhere in the world is there a more favourable place for such a project than the Bay of Fundy, for here are the world's greatest tides. Various circumstances determine that the bay itself is not an ideal site, but near its mouth, at the eastern end of the boundary between Canada and the United States, lie Passamaquoddy and Cobscook Bays. Separated from the Bay of Fundy and from each other by a series of islands and promontories, and with a mean tidal amplitude of about 20 feet, these bays are an ideal site for tidal power.

Since the 1920's when Dexter Cooper first advocated a tidal power project, the possibility of harnessing the tides has been under general consideration or serious survey almost continually. In 1956, the governments of Canada and the United States of America referred the matter to the International Joint Commission, requesting examination "To determine the effects, beneficial or otherwise, which such a power project might have on the local and national economies in the United States and Canada, and, to this end, to study specifically the effects which the construction, maintenance, and operation of the tidal power structures might have upon the fisheries in the area".

The Commission established two boards. The International Passamaquoddy Engineering Board was directed to consider the engineering and economic feasibility of the project. The International Passamaquoddy Fisheries Board was charged with the task of forecasting the effects upon the fisheries of the region.

The Fisheries Board consisted of two national sections: for Canada, J. L. Hart, Chairman, and A. L. Pritchard; for the United States, A. J. Suomela, Chairman to August 1957, D. L. McKernan, Chairman, J. L. McHugh, alternate for Mr McKernan, and M. B. Pike.

[1]Received for publication February 23, 1960.
[2]International Passamaquoddy Fisheries Board, 1956–59, Scientific Report No. 1.

J. Fish. Res. Bd. Canada, 17(2), 1960.
Printed in Canada.

The International Passamaquoddy Fisheries Board worked through a Research Committee of government scientists, representing the two national sections: for Canada, S. N. Tibbo, Chairman, L. R. Day, W. F. Doucet, R. A. McKenzie, and R. W. Trites; for the United States, L. W. Scattergood, Chairman, D. F. Bumpus, H. W. Graham, C. J. Sindermann, B. E. Skud, and J. E. Watson. For the most part the research program was carried out as a co-operative effort of the Fisheries Research Board of Canada and the United States Bureau of Commercial Fisheries. Co-operating agencies undertaking special assignments were: the Woods Hole Oceanographic Institution, non-tidal drift in the Bay of Fundy and Gulf of Maine; the Hydrographic Service of the Department of Mines and Technical Surveys of Canada, tides and tidal currents in Passamaquoddy Bay and its approaches; the Maine Department of Sea and Shore Fisheries, probable effects of construction on minor fisheries in the United States; the Conservation and Development Service of the Department of Fisheries of Canada and the United States Bureau of Commercial Fisheries, jointly, passes for anadromous fishes; the Economics Service of the Department of Fisheries of Canada, economic effects of dams on Canadian fisheries; and the Department of Economics of Bowdoin College, economic survey of the Maine sardine fishery.

The Research Committee studied oceanography, fishery biology, and fishery economics in that order. Oceanographers predicted the changed environment that would follow construction; biologists predicted the effects of the new environment upon the fisheries; and the economists translated the fishery changes into dollar values.

The plan selected by the Engineering Board called for separation of Passamaquoddy and Cobscook Bays from the Bay of Fundy and from each other by dams. Filling gates would allow the sea to enter Passamaquoddy Bay during part of each high tide, and Cobscook Bay would be drained through emptying gates during part of each low tide. Thus, Passamaquoddy Bay would remain at a higher level than Cobscook Bay and it would be possible to develop electric power at low-head turbine-generator units in a powerhouse between the two bays. International Passamaquoddy Fisheries Board scientists forecast the new oceanographic regime in the region assuming the dams in place. On the basis of that forecast, the effects on various fish stocks and fisheries were deduced.

It is expected that the dams will change the oceanographic features within parts of the Quoddy Region which includes the area inside a line from Point Lepreau, N.B., to Northern Head, Grand Manan, N.B., thence to West Quoddy Head, Maine. Major changes are anticipated inside Passamaquoddy and Cobscook Bays and immediately outside the dams. Effects outside the Head Harbour–Bliss Island line will probably be insignificant.

The mean water level of Passamaquoddy Bay will be about 6 feet higher, the mean level of Cobscook Bay about 5 feet lower. Mean "tidal" range in high and low pools will be reduced to approximately 4 and 8 feet respectively. Tidal range in the Bay of Fundy may increase by approximately 1% with a maximum increase at the head of the bay of less than a foot.

Current patterns in Passamaquoddy and Cobscook Bays and in the approaches will be altered markedly. The emptying and filling gates will be closed for about 9 and 9½ hours respectively during each tidal cycle of 12½ hours. Water will leave Passamaquoddy Bay and enter Cobscook Bay continuously through the powerhouse. When the gates are open velocities in most areas should be only slightly lower than at present. The residual counter-clockwise circulation in Passamaquoddy Bay probably will be more pronounced. Tidal streams in the outer Quoddy Region probably will be altered by not more than 20%. No measurable change in non-tidal circulation is anticipated for the Bay of Fundy.

Reduced velocities in Passamaquoddy and Cobscook Bays will result in decreased vertical mixing, increased stratification, and hence greater seasonal variations in surface water temperature. The summer maximum is likely to be about 68°F while in winter an ice cover is expected over part of these bays. Outside the dams, little change is expected, but adjacent to the emptying and filling gates there will be slightly greater seasonal variations.

Mean surface salinities for both pools will be reduced but bottom salinities are likely to be altered only slightly. It is doubtful if fresh water will penetrate below 30 to 50 feet. Flushing time is expected to increase substantially. Outside the dams, no significant change is expected, but near the emptying gates there will be a slight reduction in salinity.

Dissolved oxygen concentrations in deep water inside the dams may be lowered somewhat, especially during periods of maximum freshwater discharge. However, dissolved oxygen is unlikely to fall below 50% saturation.

The herring population is produced outside the Quoddy Region, probably off southwest Nova Scotia. General abundance of herring in the Bay of Fundy and the Gulf of Maine is unlikely to be affected.

Echo-sounder records show that most of the herring in Passamaquoddy Bay are in the open waters where no fishing takes place. Tagging experiments show that herring move freely throughout the Quoddy Region during the fishing season.

There are unlikely to be significant changes in oceanographic conditions outside the dams, hence herring should arrive in this area as before. Little change is expected in current velocities in the approaches to the filling gates when open. Since velocities are well above the maximum sustained swimming speed of herring, the fish will be carried through the filling gates. Since the filling gates are open for only about 6 hours each day, movement of herring into Passamaquoddy Bay is expected to be delayed. This is also true for Cobscook Bay where entry will be chiefly through turbines. Although the rate at which herring accumulate will be slower, the rate of movement out of these bays will be reduced also. Therefore no reduction in overall abundance is expected inside the bays.

Predicted changes in temperatures and salinities are expected to make the areas inside the dams no less favourable for herring except in isolated areas where high temperatures and low salinities may cause some mortality. Predicted pressures and rates of pressure change between the turbine intakes and exits are within limits which herring can withstand.

No relationship between herring landings and various meteorological and oceanographic conditions, including surface drift, river discharge, wind speed and direction, zooplankton, temperatures, and salinities is apparent. Year-to-year variations in individual weir catches and in total catches in various parts of the Quoddy Region have been of far greater magnitude than changes anticipated after construction of the dams.

No measurable change in groundfish landings in the Quoddy Region is anticipated, but a change in species composition of the fraction of the catch taken inside the dams is expected. Inside the dams, winter flounder fisheries may increase, but haddock and pollock fisheries will be greatly reduced. Clam fisheries will be greatly reduced for a period of 10 years and then may become re-established at a lower level of production. Scallop stocks should increase substantially. Inside the dams, a modest increase in production of lobsters is anticipated. Conditions for anadromous species such as Atlantic salmon and alewives may be improved, and smelt, shad, and sea-run trout stocks should increase. Striped bass and tom cod thrive in areas where conditions of temperature and salinity are similar to those predicted for Passamaquoddy and Cobscook Bays. Some reduction is expected in availability of marine worms and rockweed.

Six existing herring-weir sites will be eliminated when the dams are constructed. Other weirs must be relocated or altered to suit the new oceanographic environment. Weir stakes and nets will have to be increased in size to suit new water levels. Resultant fixed costs are estimated at $129,000. Wood borer activity is expected to increase. Ice will cause some damage to weir materials in winter. Annual costs of weir operation will rise approximately $10,000. It is conceivable that weir owners may discontinue their investments in weirs inside the dams. A shift to alternative methods of fishing could be expected to maintain the fishery, at least at its present level, and as the abundance of herring is not expected to change appreciably, herring catches can be increased substantially if the market is favourable.

Lobster fishermen are not expected to be adversely affected, but physical damages due to relocation of lobster pounds, refrigeration of water, or extension of intake pipes are expected to cost $450,000. Changes in the clam fishery may result in a loss of capital investment in plants valued at $100,000 and an annual loss in primary production of $104,000 for 10 years. Disappearance of some groundfish from inside the dams will reduce the value of annual landings by approximately $3,000.

Fish passage facilities for anadromous species were estimated by fisheries engineers to cost $3.0 million but the Engineering Board believes that substantial construction economies can be achieved by planning for fish passes in original construction specifications.

If the Digdeguash pumped-storage auxiliary project is selected as a method of providing auxiliary power, it will be necessary to consider the effects on local salmonoid stocks including the advisability of providing fishways in this dam.

If the proposed Passamaquoddy power project is approved, oceanographic and fishery investigations should be resumed to provide a more accurate basis for prediction and assessment. After the project is complete, it will be extremely important to conduct detailed investigations of the changes in the circulation and in the fisheries. The information thus obtained will be of inestimable value in assessing the effects of future projects of this type, and will be of general value to fishery research everywhere.

The report of the International Passamaquoddy Fisheries Board to the International Joint Commission was based in part on work carried on with funds provided through the International Joint Commission. In addition the Fisheries Research Board of Canada and the United States Bureau of Commercial Fisheries directed much of their regular research activity into work bearing on Passamaquoddy problems. Work in parasitology, serology, plankton oceanography and explorations in the Gulf of Maine was carried out in part with Saltonstall–Kennedy funds. Results of these studies were used by the International Passamaquoddy Fisheries Board in reaching conclusions.

Investigations under the International Passamaquoddy Fisheries Board led to new researches and new reviews. These will be published in various journals as scientific reports in a numbered series beginning with this introductory account. Number 2 in the series will be the Report of the International Passamaquoddy Fisheries Board, presented to the International Joint Commission in October 1959, which will be issued as a Special Scientific Report — Fisheries of the U.S. Fish and Wildlife Service. Five reports have already been published:

SINDERMANN, CARL J. Diseases of fishes of the western North Atlantic. V. Parasites as indicators of herring movements. Maine, Dept. Sea & Shore Fisheries, Research Bulletin No. 27, 30 pp., November 1957. (IPFBSR No. 3).

SINDERMANN, CARL J. Diseases of fishes of the western North Atlantic. VI. Geographic discontinuity of myxosporidiosis in immature herring from the Gulf of Maine. Maine, Dept. Sea & Shore Fisheries, Research Bulletin No. 29, 20 pp., December 1957. (IPFBSR No. 4).

McKENZIE, R. A., AND B. E. SKUD. Herring migrations in the Passamaquoddy region. *J. Fish. Res. Bd. Canada*, **15**(6): 1329–1343, 1958. (IPFBSR No. 5).

TIBBO, S. N., J. E. HENRI LEGARE, LESLIE W. SCATTERGOOD AND R. F. TEMPLE. On the occurrence and distribution of larval herring (*Clupea harengus* L.) in the Bay of Fundy and the Gulf of Maine. *J. Fish. Res. Bd. Canada*, **15**(6): 1451–1469, 1958. (IPFBSR No. 6).

SINDERMANN, CARL J., AND DONALD F. MAIRS. A major blood group system in Atlantic sea herring. *Copeia* **1959**, No. 3: 228–231. (IPFBSR No. 7).

Four additional reports (IPFBSR No. 8, 9, 10 and 11) in this series appear on pages 133–168, 169–173, 175–180 and 181–197 of this issue of this Journal.

Herring Fishery in Southern New Brunswick[1,2]

By R. A. McKenzie and S. N. Tibbo

Fisheries Research Board of Canada
Biological Station, St. Andrews, N.B.

ABSTRACT

Most of the herring taken in the Passamaquoddy area of southern New Brunswick are caught in stationary weirs built close to shore. Analyses of weir catches show no significant relationships between average catches inside Passamaquoddy Bay and catches in outside areas for the same year. Weirs inside Passamaquoddy Bay are more efficient and catch about twice as many herring per weir as those outside the Bay.

Seasonal and annual variations both in individual weir catches and in total catches in the various statistical districts of Charlotte County are far greater now than any changes that can be forecast as resulting from the installation of the proposed Passamaquoddy tidal power dams.

INTRODUCTION

One of the most important areas in eastern Canada where herring (*Clupea harengus* L.) are fished is in the Bay of Fundy. Scattergood and Tibbo (1959) reviewed the herring fishery of the northwest Atlantic including the Bay of Fundy and dealt with statistics of landings, methods of capture and utilization. The present account deals particularly with the herring fishery of the Passamaquoddy area of the Bay of Fundy (Fig. 1).

In the nineteenth century the herring fishery was chiefly for large fish that were used for a frozen herring trade with the United States. This fishery reached a peak about 1880 but declined thereafter (Huntsman, 1948). Huntsman (1953) reviewed the changes which occurred in the herring fishery of the Passamaquoddy area and showed that the utilization of the small, immature fish, known as "sardines" increased from about 5,000,000 lb in the 1880's to nearly 70,000,000 lb in the 1920's. On the other hand, landings of large, mature fish declined from about 25,000,000 lb to less than 5,000,000 over the same period.

The small herring were first used as bait and fertilizer, then as a source of fish meal and oil, and a substantial industry developed. Utilization of the small fish in large quantities, however, was directly connected with success in canning them as sardines. The first attempt at canning these sardines in North America was made at Eastport, Maine, in 1867 (Earll, 1887). It failed, but by 1875 some success was attained, and the first cannery was established. Canneries in the Passamaquoddy area increased to about 36 by the end of the nineteenth century with the consequent increase in the quantity of sardines used. While canning

[1]Received for publication December 14, 1959.
[2]International Passamaquoddy Fisheries Board, 1956–59. Scientific Report No. 8.

J. Fish. Res. Bd. Canada, 17(2), 1960.
Printed in Canada.

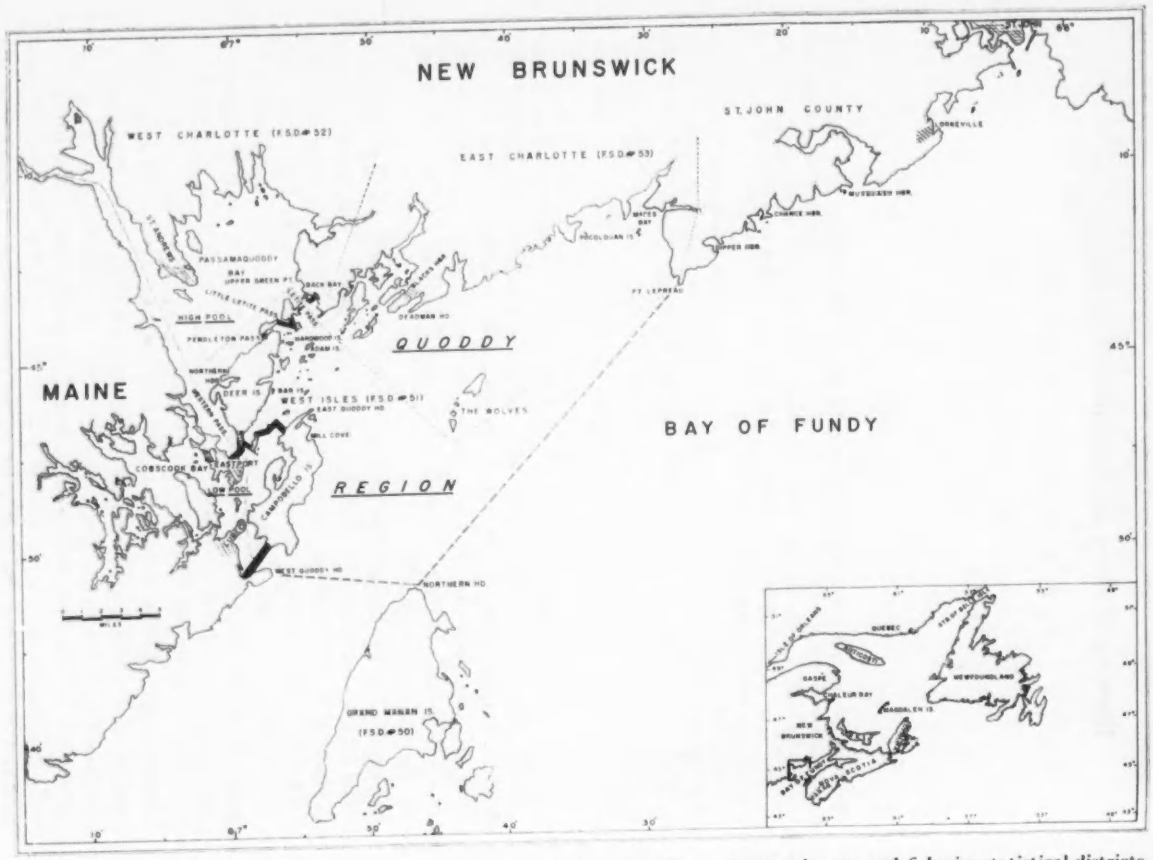

FIG. 1. Map of the Passamaquoddy region showing locations of proposed dams, impoundments and fisheries statistical districts.

sardines is still a big industry the production of fish meal and pet food is rapidly becoming equally important.

The centre of the herring industry in southern New Brunswick is located in the Passamaquoddy area where about 80% of the weight and 50% of the value of all fish landings consist of herring. This report considers the herring fishery of the Passamaquoddy area in relation to the proposed tidal power project.

METHODS OF CAPTURE

Many methods have been used for fishing both adult herring and sardines in the Passamaquoddy area. The relative importance of these methods has changed with the development of the fishery, but most of them are still in use and a brief history and description seems appropriate. Weir fishing, which accounts for most of the catch, is described in more detail.

Torching

Torching, sometimes known as "driving", was practically the only method used for taking sardines until early in the nineteenth century. Herring are attracted to a moving or flickering light at night, and when such a light is carried on a boat moving through the water, the fish are attracted to it and may be dipped into the boat. A small amount of torching is still carried on; the catch used chiefly as bait for other species.

Gill Netting

Gill nets were first used in the Passamaquoddy area about 1829. By the middle of the nineteenth century a large gill-net fishery had developed, chiefly in the Musquash-Lepreau and the southern Grand Manan areas. This fishery was concerned chiefly with large herring for a pickled-herring trade with the United States. It began to decline late in the nineteenth century and ceased altogether about 1945. Gill nets were always anchored and fishing was carried on at night in depths of 5 to 15 fathoms. The stretched mesh size of the nets varied from $2\frac{1}{4}$ to $2\frac{3}{4}$ inches.

Drag or Shut-off Seining

The first recorded attempt at drag or shut-off seining (sometimes called stop seining, Fig. 2) was about 1875 when fishermen at Deer Island used a 75-fathom seine to surround sardines and haul them on to the beach (Earll, 1887). This gradually developed into an important fishing method. Drag seining is now carried on separately but formerly it was used in association with weir fishing. Drag seines may be up to 300 fathoms in length. Stretched mesh sizes vary from $\frac{5}{8}$ to $1\frac{1}{8}$ inches.

FIG. 1. Map of the Passamaquoddy region showing locations of proposed dams, impoundments and fisheries statistical districts.

FIG. 2. Typical "sardine" fishing gear—stop seine. In the background, note the pocket for removing the herring "sardine" catch.

PURSE SEINING

United States fishermen began using purse seines about 1865 and the method spread rapidly from the Massachusetts area to the eastern part of Maine (Earll, 1887). Purse seining did not become important in southern New Brunswick, however, until about 1934. It reached a peak during World War II when 40 to 50 purse-seine boats were licensed annually by the Department of Fisheries. Purse seines are restricted by law to a length of 100 fathoms and a depth of 100 feet at the ends. Purse seining is a far more efficient method of catching herring than any of the other methods now being used and is accounting for an increasing proportion of the total catch.

WEIR FISHING

Weir fishing is, by far, the most important method of catching herring in the Passamaquoddy area (Fig. 3). Weirs were used on the Nova Scotia side of the Bay of Fundy before the beginning of the nineteenth century (Moore, 1898), but it was not until about 1820 that they were introduced into the New Brunswick area. The earliest attempts at weir fishing in the Passamaquoddy area failed, but in 1828 a large weir was built and operated successfully at Rodgers Island near

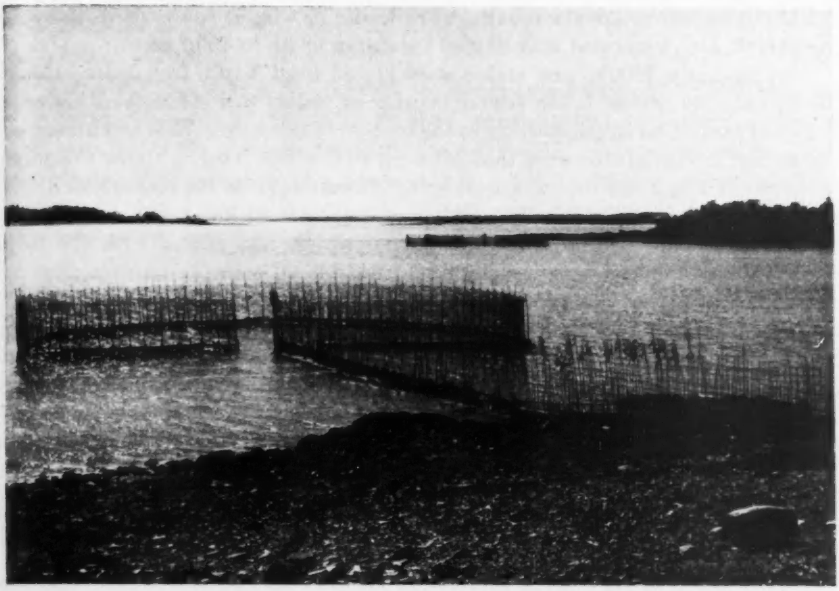

FIG. 3. Typical "sardine" fishing gear—weir. In the foreground, a simple weir without a parlour. In the background, a compound weir with a parlour in which herring are held alive awaiting sale.

North Lubec, Maine. The number of weirs in Charlotte County increased rapidly from 55 in 1849, to 142 in 1880 and to 239 in 1893. More than 1,100 weir sites have now been registered. The maximum number of weirs used in any one season, however, was in 1920 when 476 weir licenses were issued. At the present time from 300 to 400 weirs are licensed annually in Charlotte County.

In weir fishing the fish are led by long leaders or wings through a funnel-shaped entrance into a trap. Extensions of the wings into the trap form a "hook" which directs the fish past the entrance as they swim around inside. The most favourable locations for weirs are near the mouths of rivers, in small bays or coves, and around the shores of islands.

The form of a weir varies according to the location and hence the names "Bar weir", "Channel weir", "Shore weir", etc., are indicative of the general shape, size and positioning. A weir location is usually chosen after a careful study of the movements of herring in a particular area and the weir is built so that there is the greatest chance that fish will be led into it.

Many changes have taken place in the methods of constructing weirs, although the general shape and type have remained the same. The stakes at the mouth of the weir are usually driven first. These vary from 15 to 40 feet in length, depending on the depth of the water, are placed from 10 to 15 feet apart and are driven from 6 to 8 feet into the bottom. When the bottom is hard, the stakes are secured to heavily ballasted platforms. The enclosure or "pound"

is laid out to seaward of the mouth. The leader or wing is run towards shore or towards shoaler water and may extend for distances up to 400 feet.

In the early 1900's, weir stakes were placed from 3 to 6 feet apart. After the stakes were driven, brush (usually spruce or cedar) was interwoven horizontally and pushed down underwater to the bottom of the weir. This was known as "spudging". The stakes were thus filled up to low tide level. Above this level rib bands at 1 to 2 feet intervals were spiked horizontally to the stakes and brush was fastened to these vertically. Only vertically placed brush was used in the leaders or wings. The bottom brush (under water) was placed with the tops down while the upper brush (usually birch) was placed with the tops up.

The first major change in this type of weir construction occurred about 1920 when for many weirs the spacing of stakes in the pound was increased to 6 to 8 feet. "Spudging" was often replaced by racks which were built on shore. These racks consisted of vertical rack legs at about 4-foot intervals to which brush was spiked horizontally. The racks were about 18 feet in width and a little longer than the depth of water at low tide. They were floated out to the weir, hoisted to a vertical position, dropped into place along the outside of the stakes and fastened at the top to the horizontal rib bands and stakes. Such racks were released from the rib bands in the autumn and allowed to sink where they remained over winter. The next season they were again lifted into place. In this way, they could be used for a number of years. The top brush was replaced with netting. Poles long enough to reach above extreme high water were spiked to the top of each stake. The netting fastened to these extended from the top of the racks to extreme high water level. In some instances netting replaced the upper brush on the leaders and wings.

A further change in weir construction began about 1935. Again this involved the underwater part of the weir. The stakes and rib bands remained the same but instead of spudging or racking, the bottom of the weir was enclosed with cotton netting. In shallow water where there was little current, this netting was held down with heavy chain along the bottom, but in most situations, a diver fastened the bottom of the netting to each stake at the ocean floor. The top was attached to the rib bands just above low water. Even in the leaders and wings some netting was used to replace brush below low tide level. This underwater netting was much heavier than that used in the upper part of the weir. About 1952, nylon, netting, which does not deteriorate like cotton, was introduced to replace the cotton netting at the bottom. However, the top netting is still mostly cotton.

To remove the trapped fish from weirs, purse seines varying in length from 18 to 22 fathoms and in depth from 20 to 45 feet, are used at low water. The seine is taken by boat from a reel on shore or a raft into the weir where it is stretched around the sides until the ends are brought together and the fish encircled. The seine is then pursed. When the fish are "dried up" in a sufficiently compact body, they are dipped with large brails into the boat. About 1947–48 suction pumps gradually replaced the brails in transferring the herring from the seine into the carrier. Now pumps have almost completely replaced brails in handling herring at the weirs.

QUANTITIES LANDED

Following World War I there was considerable improvement in the methods of collecting fisheries statistics in Canada. Department of Fisheries officers, each responsible for a small district, collected monthly records based on interviews with fishermen and processors. This method remained essentially the same until 1956 when a purchase slip system was introduced in some districts. This system has now been extended to most of the fishery districts in eastern Canada. Statistics are submitted to the Department of Fisheries regional offices and compiled on monthly and annual bases by the Dominion Bureau of Statistics.

In addition to the monthly statistics, records of individual daily weir catches were obtained in 1957 and 1958 for Charlotte and Saint John Counties. These have been especially valuable in the present study both for establishing the exact location of the catches and for showing variations in landings with time.

Annual Landings

Data from Scattergood and Tibbo (1959) for the years 1920 to 1954 together with information for the years 1955 to 1958 show that the average herring catch for the Canadian Atlantic area including Newfoundland and Labrador has been 217,000,000 lb. Of this amount, slightly more than 78,000,000 lb or 36% was taken in the Bay of Fundy and chiefly in Charlotte, Saint John, Digby, and Yarmouth Counties.

Bay of Fundy landings. A study of the landings in the Bay of Fundy over the 1920-58 period shows (Table I) that the most of the herring catch was made near the entrance to the Bay. Charlotte and Saint John Counties accounted

Table I. Average landings of herring by counties in the Bay of Fundy area, 1920–58. (+ denotes amounts < 0.1%.)

County	Average landings	
	lb	%
Yarmouth	4,837,100	6.2
Digby	6,120,800	7.9
Annapolis	1,578,500	2.0
Kings	297,000	0.4
Hants	4,600	+
Colchester	11,200	+
Cumberland	19,400	+
Westmorland	1,100	+
Albert	1,800	+
Saint John	4,308,000	5.5
Charlotte	60,947,200	78.0
Totals	78,126,700	100.0

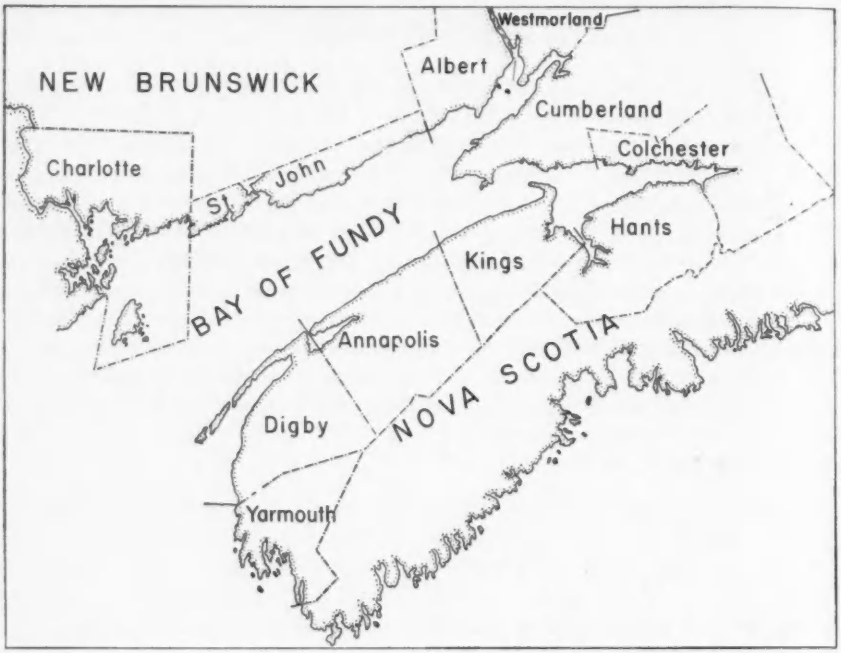

FIG. 4. Map showing counties bordering the Bay of Fundy.

for 83.5% of the catch and Digby and Yarmouth Counties accounted for 14.1%. The balance of the catch (2.4%) was made chiefly in Annapolis and Kings Counties, with very small quantities taken in the other counties bordering on the Bay of Fundy (Fig. 4). A comparison between landings on both sides of the mouth of the Bay of Fundy is given by 5-year periods in Table II. There was

TABLE II. Comparison of herring landings on Nova Scotia and New Brunswick sides of the mouth of the Bay of Fundy by 5-year periods from 1920 to 1958 inclusive.

Period	Nova Scotia (Yarmouth & Digby)	New Brunswick (Charlotte & Saint John)
	lb	*lb*
1920–24	2,189,200	53,146,400
1925–29	4,590,200	59,748,600
1930–34	3,109,200	41,785,200
1935–39	3,576,800	62,262,600
1940–44	11,675,600	86,097,200
1945–49	13,069,000	91,914,200
1950–54	17,200,400	76,405,000
1955–58 (4 years)	37,577,000	47,039,500

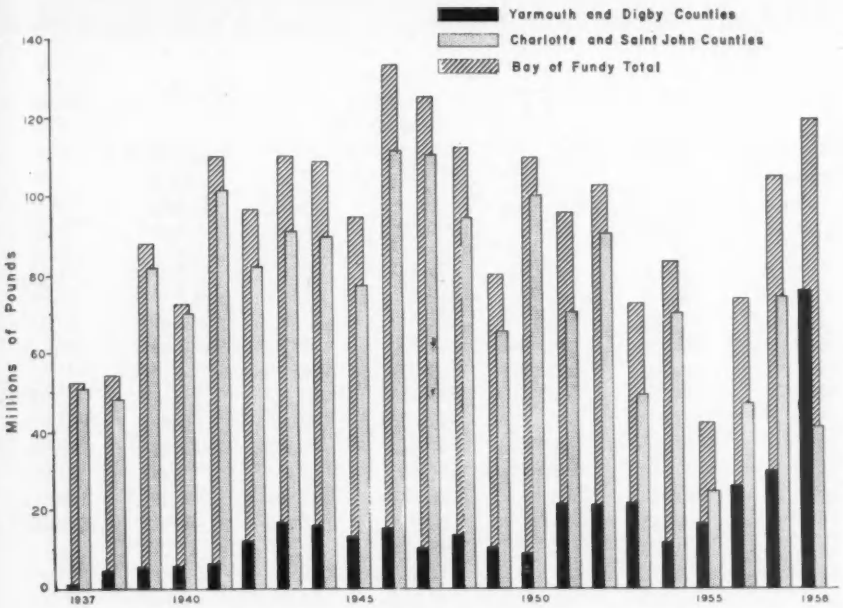

FIG. 5. Annual herring landings from 1937 to 1958 on the Nova Scotian side of the mouth of the Bay of Fundy (Yarmouth and Digby Counties), on the New Brunswick side (Charlotte and Saint John Counties) as well as the totals for the Bay of Fundy.

no trend in the landings for both areas until the beginning of World War II when landings increased substantially. This increase continued in Nova Scotia but in New Brunswick it reached a peak in the late 1940's and since then catches have dropped below the average pre-war level. Figure 5 shows the annual herring landings for the 1937 to 1958 period in Yarmouth and Digby Counties on the Nova Scotia side of the Bay of Fundy and in Charlotte and Saint John Counties on the New Brunswick side. Total landings for the Bay of Fundy are included in Fig. 5.

SOUTHERN NEW BRUNSWICK LANDINGS. Table III gives the annual herring landings in Charlotte and Saint John Counties by statistical districts for the 1937–58 period. During this period, total landings reached a peak of nearly 112,000,000 lb in 1946. The smallest catch was in 1955 when less than 25,000,000 lb were landed. A percentage breakdown of landings gives 29% for Charlotte East; 27% for Grand Manan; 23% for West Isles (all of the islands at the entrance to Passamaquoddy Bay); 15% in Charlotte West (chiefly Passamaquoddy Bay) and 6% in Saint John County. The extreme variations in landings for individual areas should be noted. For example, Charlotte East landings varied from

3,900,000 to 41,800,000 lb, while Charlotte West landings varied from 3,000,000 to 28,200,000 lb.

TABLE III. Herring landings in Charlotte and Saint John Counties, 1937–58. Landings in thousands of pounds.

	Charlotte County					
Year	Charlotte East	Charlotte West	West Isles	Grand Manan	Saint John County	Total
1937	5,152	6,247	19,395	16,663	3,897	51,353
1938	27,101	4,602	4,986	7,912	3,740	48,340
1939	29,074	7,614	22,613	20,888	1,845	82,033
1940	21,164	8,138	8,560	25,076	2,542	65,481
1941	30,321	9,228	34,948	24,949	2,230	101,676
1942	38,396	7,180	15,376	16,202	5,148	82,303
1943	22,065	8,921	27,426	27,016	5,698	91,125
1944	29,403	4,222	38,505	15,687	2,084	89,901
1945	29,586	3,409	20,869	22,475	1,137	77,476
1946	39,713	7,821	40,697	21,563	1,897	111,691
1947	41,844	17,075	30,958	12,045	8,547	110,469
1948	30,527	12,546	13,070	35,150	3,157	94,450
1949	17,656	3,032	14,486	23,794	6,513	65,481
1950	25,902	11,943	17,702	32,407	12,102	100,056
1951	13,021	24,091	17,135	10,867	5,389	70,503
1952	22,196	28,159	10,029	20,520	9,676	90,580
1953	11,991	12,953	7,370	11,685	5,864	49,863
1954	4,226	11,889	4,436	43,540	6,932	71,023
1955	3,908	7,029	4,291	7,551	1,974	24,753
1956	16,301	5,756	10,752	12,706	1,957	47,472
1957	10,893	26,399	11,520	20,474	5,083	74,369
1958	9,920	10,033	2,372	13,298	5,941	41,564
Average	21,834	10,831	17,159	20,112	4,698	74,635
Percentage	29.2	14.5	23.0	26.9	6.4	100

QUODDY REGION LANDINGS. Because the proposed Passamaquoddy tidal power dams will divide the area into pools which will not coincide with existing fisheries statistical districts, an attempt was made to allocate the annual herring landings for the 1947–58 period to these new areas. This was done from the detailed landing records for 1957 and 1958 plus information received from a large sample of weir fishermen who were interviewed primarily for an economic survey of the herring fisheries.

Table IV and Figure 6 show the 1947–58 herring landings in various parts of the Quoddy Region (all of the area inside a line drawn from Point Lepreau, N.B., to Northern Head, Grand Manan, and thence to West Quoddy Head, Maine) and in the remainder of Charlotte County and in Saint John County. The

TABLE IV. Herring landings (in thousands of pounds) for 1947–58 in Charlotte and Saint John Counties, arranged according to the proposed Passamaquoddy tidal power structures.

	Charlotte County					
	Quoddy Region					
Year	High pool	Low pool	Outside	Grand Manan	Saint John County	Total
1947	21,000	800	68,100	8,600	12,000	110,500
1948	9,800	< 100	46,100	3,000	35,500	94,400
1949	5,200	600	29,200	6,600	23,800	65,400
1950	8,800	< 100	46,200	12,200	32,800	100,000
1951	28,400	< 100	26,300	5,000	10,800	70,500
1952	19,500	< 100	41,300	9,600	20,200	90,600
1953	9,800	1,400	20,900	5,900	12,000	50,000
1954	6,400	200	13,800	7,000	43,600	71,000
1955	8,400	< 100	6,800	2,000	7,600	24,800
1956	4,500	800	28,900	2,200	13,100	47,500
1957	26,400	1,600	21,000	5,000	20,400	74,400
1958	10,000	400	11,700	5,900	13,300	41,300
Average	13,200	800[a]	29,800	6,100	20,400	70,000
Percentage	18.8	1.1	42.4	8.7	29.0	100

[a]Quantities less than 100,000 lb not included in average or totals.

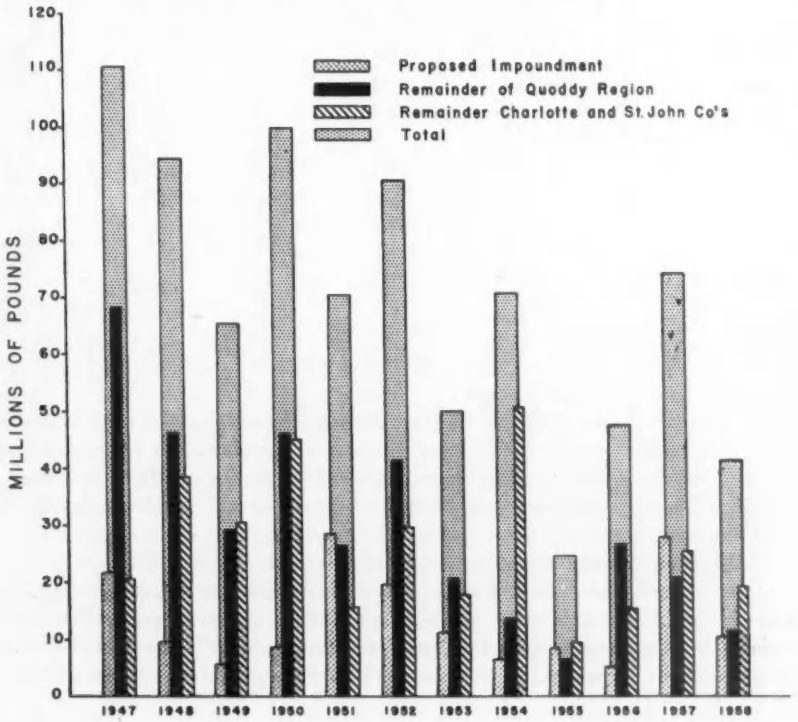

FIG. 6. Annual herring landings from 1947 to 1958 within the impoundment (high and low pools), in the remainder of the Quoddy Region and also in the remainder of Charlotte and Saint John Counties.

detailed distribution of the landings for each year is given in Plates I to XII at the end of the paper. Of special interest is the high pool catch which averaged 13,200,000 lb or 18.8% of the total, the low pool catch which averaged 800,000 lb or 1.1% of the total and the outer Quoddy Region catch which averaged 29,800,000 lb or 42.4% of the total (Fig. 1). Nearly two-thirds (62.3%) of the total herring catch in southern New Brunswick is, therefore, taken in the Quoddy Region.

There are large variations in annual landings from the various parts of the Quoddy Region. High pool landings varied from 4,500,000 to 28,400,000 lb, low pool landings varied from less than 100,000 lb to 1,600,000 lb, and outer Quoddy landings varied from 6,800,000 to 68,100,000 lb.

Monthly Landings

Southern New Brunswick landings. Table V shows that the herring landings in the various statistical districts of Charlotte and Saint John Counties varied from month to month, being greatest in the summer and poorest in the

Table V. Average monthly herring landings in Charlotte and Saint John Counties, 1937–58 (thousands of pounds).

	Fisheries Statistical Districts					
Month	Saint John County	Grand Manan	West Isles	Charlotte West	Charlotte East	Total
January	88	367	126	3	1,127	1,711
February	23	394	14	0	1,493	1,923
March	209	552	12	41	1,927	2,742
April	173	664	237	88	1,687	2,848
May	216	360	1,188	396	1,601	3,762
June	785	1,020	1,443	911	1,783	5,942
July	840	3,589	2,570	1,273	2,986	11,259
August	1,037	5,549	3,869	1,635	4,112	16,203
September	847	4,034	3,449	3,139	2,856	14,325
October	395	2,208	1,973	2,194	1,459	8,229
November	48	1,190	1,431	863	449	3,982
December	54	285	559	84	323	1,304

winter. In Charlotte West, West Isles, Grand Manan and Saint John, 70 to 76% of the landings were made from June to September. In Charlotte East, however, only about 53% of the landings were made during these months. A purse-seine fishery produced substantial landings in this district during the winter months.

Within some of the statistical districts there are seasonal differences which are quite regular and well known among the fishermen. As a rule the weir fishery in Saint John County takes place during the summer and autumn, especially in the Lorneville and Musquash areas. Near Dipper Harbour and Chance Harbour, however, it may be both earlier and later. Purse seining is

usually carried on in Saint John County from late summer to late winter. It is most actively pursued, however, when herring are scarce in Charlotte County, which is closer to the canneries at Blacks Harbour.

At Grand Manan, herring are taken at almost all times of the year, principally in weirs from May to November and in purse seines during the winter and early spring.

QUODDY REGION LANDINGS. Maximum monthly landings in the Quoddy Region occur in August. The fishery in Charlotte West (Passamaquoddy Bay) is an exception to this with peak landings being made in September and comparatively large landings in October. Since almost all the high pool landings are made in Charlotte West, it follows that the maximum monthly landings in this pool are made a month later than those outside the proposed dams. However, some weirs close to deep water, such as the Protection weir off St. Andrews Point and the Mascarene weir off Upper Green Point just inside Letite Passage, are known as early weirs. Their catches are made both as the fish move into the Bay in spring, and during the summer and early autumn. On the high-pool side of Deer Island, the fishery is small because the shore is generally unsuitable for weirs. This fishery usually takes place during the summer now, although at one time there was an autumn fishery in Northern Harbour. In Pendleton and Little Letite Passages the main fishery takes place in the autumn as the fish move out of Passamaquoddy Bay.

Immediately outside of Passamaquoddy Bay the herring fishery is generally most active in late summer and autumn. Exceptions to this are associated mainly with the fish entering Passamaquoddy Bay in the spring. For example, at Mill Cove on the eastern end of Campobello Island herring are often caught in the spring. This also occurs at Bar Island between Deer Island and Campobello Island and at the eastern ends of Adam Island and Hardwood Island. The appearance of herring in the weirs at these locations in the spring is an indication to fishermen that the fish are moving into Passamaquoddy Bay.

Herring are usually present in the outer Quoddy Region during the winter but are in deep water where they may be taken with purse seines or by torching, not by weirs.

In Charlotte East (Back Bay to Point Lepreau) herring are abundant throughout the year as indicated by the landings in Table V. The weir fishery in this district usually begins earlier than in other areas. One weir, located just northeast of Pocologan Island close to deep water, but protected from storms by ledges, is often fished late in winter (March). This is about the only location in the Quoddy Region where a weir can be operated successfully during the winter. Late in April or early May other weirs are fished as the herring move into shallow water and fishing continues until late September or October. Purse seining sometimes begins in November and continues into April. It is most active from Deadman Head to Maces Bay in depths of 60 to 160 feet.

In Saint John County and in Grand Manan, the period of high catches may be slightly longer than in the Quoddy Region, beginning in July and continuing into September.

Landings by Gear

Detailed records of landings by gear in southern New Brunswick are available only for 1957 and 1958. Some information is available, however, to indicate the relative importance of the various methods of fishing.

Torching. The amount of torching for herring carried on in the Quoddy Region depends on markets for bait used in lobster fishing and in line-trawling for groundfish species. Most of the torching is done in the autumn and winter and catches sometimes amount to 10,000 to 15,000 lb per boat per night's fishing. Although torching has declined drastically in Saint John and Charlotte Counties, there are a few boats which still operate. No records of monthly or annual landings are available.

Gill netting. The gill-net fishery in the Quoddy Region ceased about 1945. No records are available to show the amount of herring taken in gill nets but it was probably small especially in the 1930's and early 1940's.

Drag or shut-off seining. The numbers of shut-off and drag-seining licenses issued by the Department of Fisheries gives some indication of the importance of this method of fishing, although, except for 1957 and 1958, no catch records are available. Essentially, there is no difference between drag seining and shut-off seining although licenses have been issued for both. Up to 1954, shut-off licenses were issued along with weir licenses and shut-off seines were used in association with weir fishing. Since 1954 separate licenses (now called drag-seining licenses) have been issued and fishermen are not permitted to use the seines within 1,000 feet of an operating weir. This has resulted in a substantial reduction in the numbers of licenses issued but there has perhaps been little change in the number of gear units operated or the amount of fish caught. The numbers of shut-off licenses issued for the period 1947 to 1954 are given in Table VI.

Table VI. Numbers of shut-off licenses issued from 1947 to 1954 inclusive in Saint John and Charlotte Counties.

Year	Saint John County	Charlotte County				Total
		Grand Manan	West Isles	Charlotte West	Charlotte East	
1947	3	0	4	22	52	81
1948	3	38	3	55	52	151
1949	3	25	1	26	68	123
1950	2	21	11	48	69	151
1951	...	10	25	20	73	128
1952	...	9	2	44	68	123
1953	...	19	16	36	79	150
1954	...	...	25	14	72	111

Some records of the operation of shut-off seines are available. Although these are by no means complete, it is probable that not more than 25 or 30% of the shut-off seines licensed were ever operated. For example, in 1948 there were 151 licenses issued for all areas and 45 seines operated. In 1953, 79 licenses were issued in Charlotte East but only 20 seines were operated there.

From 1955 to 1958 inclusive, when only drag-seining licenses were issued, the number of licenses for both Charlotte and Saint John Counties has varied from 22 to 47.

Table VII gives the total landings by drag seines in Charlotte and Saint John Counties for 1957 and 1958.

TABLE VII. Landings of herring caught by drag seines in Charlotte and Saint John Counties 1957 and 1958.

District	Landings		
	1957	1958	Average
Saint John	179,000	1,850,000	1,015,000
Grand Manan	596,000	...	596,000
West Isles	15,000	182,000	99,000
Charlotte West	3,137,000	55,000	1,596,000
Charlotte East	321,000	437,000	379,000
Total	4,248,000	2,524,000	3,386,000

The drag-seine fishery is carried on almost entirely from June to October with more than 59% of the landings being made in September. In 1957 most of the catch (74%) was made in Charlotte West while in 1958 the largest landings were made in Saint John County (73%). The average catch per seine licensed in 1957 was approximately 150,000 lb while in 1958 it was approximately 80,000 lb. This compares favourably with the average catch per weir. The total drag-seine catch made up only a small proportion (less than 6%) of the total herring catch for the two years.

PURSE SEINING. Purse seining in southern New Brunswick waters reached a peak during World War II when 40 to 50 boats were licensed annually. In the post-war years (1947 to 1958) fewer purse seiners have operated and the records show that the numbers have varied from 9 to 21, except in 1950 when no purse-seine licenses were issued.

Since purse seiners are fairly large they can operate anywhere in the Bay of Fundy. Partly because of local opposition to their method of fishing, they tend to stay away from areas where there are large numbers of weirs. A substantial proportion of the purse-seine catch is made on the east side of the Bay of Fundy, off Digby and Yarmouth Counties. The New Brunswick catches are made

chiefly in Charlotte East and in Saint John Counties during the winter months when few if any weirs are in operation.

Although no record of purse-seine landings is available prior to 1957, the extent of purse-seine operations can be approximated by examining the landings for the months of December to April inclusive. Table VIII gives the herring landings for Charlotte and Saint John Counties during the winter seasons from 1947 to 1958. These landings were made chiefly, if not entirely, by purse seiners.

TABLE VIII. Herring landings in Saint John County and the districts of Charlotte County during the winter seasons 1946–47 to 1957–58, in thousands of pounds. (Winter = December to April inclusive.)

Seasons	Saint John County	Grand Manan	West Isles	Charlotte West	Charlotte East	Total
1946–47	224	57	2,953	36	13,156	16,426
1947–48	875	940	1,407	237	17,791	21,250
1948–49	1,039	563	2,798	289	4,060	8,749
1949–50	0	9	363	86	185	643
1950–51	21	214	263	232	1,779	2,509
1951–52	5,641	1,430	1,507	827	14,030	23,435
1952–53	1,233	476	68	58	576	2,411
1953–54	0	1,264	220	50	1,550	3,084
1954–55	0	2,031	283	28	985	3,327
1955–56	385	0	281	704	10,363	11,733
1956–57	249	1,830	337	175	5,109	7,700
1957–58	0	531	15	0	2,298	2,844
Average	806	779	875	227	5,990	8,676
Percentage	9.3	9.0	10.1	2.6	69.0	100

The landings vary considerably both for individual areas and for seasons. The most successful seasons were 1947–48 and 1951–52 when more than 20,000,000 lb of herring were landed. These figures are minimum landings because they do not take into account the catches that were made by purse seiners from May to November. The percentage of the total herring catch contributed by purse seiners varies considerably, but may be as much as 25% in some years. This is especially significant in view of the small numbers (9 to 21) of purse seiners as compared with the large numbers (300 to 400) of weirs.

Table VIII also shows that 69% of the purse-seine catches are made in Charlotte East with only minor catches (average 2.6%) in Charlotte West (Passamaquoddy Bay).

Table IX shows the total purse-seine landings for 1957 and 1958. The differences between these figures and the totals for these two years given in Table

TABLE IX. Landings of herring caught by purse seines in Charlotte and Saint John Counties 1957 and 1958.

District	Landings		
	1957	1958	Average
	lb	*lb*	*lb*
Saint John	125,000	1,517,000	821,000
Grand Manan	2,169,000	874,000	1,522,000
West Isles	12,000	22,000	17,000
Charlotte West	63,000	2,272,000	1,167,000
Charlotte East	5,816,000	3,198,000	4,507,000
Totals	8,185,000	7,883,000	8,034,000

VIII represent the amount of the purse-seine catches during the period May to November. This amounted to 618,000 lb in 1957 and 4,337,000 lb in 1958.

Since purse seiners operate for most of the year in other areas the catches made in southern New Brunswick represent only a small part of their effort. It is significant, however, that this small part is, on the average, 3 or 4 times larger than the average annual weir catch in southern New Brunswick.

WEIR FISHING. For many years weirs have been the most important gear used for catching herring in southern New Brunswick. The weir fishery usually begins late in April or early in May and continues into November, occasionally into December. Weir operation is impossible during the other months, partly because of weather conditions but also because the herring spend the winter months in deeper water where weirs cannot be built.

Because of its importance in the herring fishery a great deal of information about the weir fishery has been recorded. In the development of the weir fishery many weir sites have been used and altogether there are now more than 1,100 registered sites in Charlotte and Saint John Counties. Some of these sites were abandoned altogether after a few trials, while others have been fished intermittently. Many weirs have a long history of continuous operation even though in some years they caught no fish.

The Department of Fisheries records show the locations and operations of each weir site. Each weir is named and in spite of the large number of operating weirs and approved locations, there is surprisingly little duplication of names. Some picturesque names, such as "Grab-all" and "Poor and Needy", probably describe the catches made at some period during their operation.

For most years and districts complete records are available not only for weirs licensed but also for weirs that were built and operated. Table X gives the numbers of weirs licensed from 1947 to 1958 in Charlotte and Saint John Counties. In recent years from 300 to 400 weirs (occasionally more) have been

licensed annually; the average for the whole period is 391. Records of weirs built and operated are incomplete, but show an average number of about 350 weirs built each year.

Table XI shows the number of weirs that have been licensed in Charlotte and Saint John Counties for various periods since 1947. Of the 689 weirs that have been licensed at some time since 1947, only 144 (20.9%) have been licensed every year, while 143 (20.7%) were licensed for only one year out of 12.

TABLE X. Numbers of weirs licensed in Charlotte and Saint John Counties, 1947 to 1958 inclusive.

Year	Saint John County	Grand Manan	West Isles	Charlotte West	Charlotte East	Total
1947	31	33	178	105	145	492
1948	22	70	132	53	102	379
1949	21	85	136	61	96	399
1950	23	94	123	66	95	401
1951	22	95	128	76	94	415
1952	25	91	116	59	100	391
1953	24	84	98	67	93	366
1954	23	93	95	70	85	366
1955	33	88	102	64	83	370
1956	27	90	102	62	86	367
1957	21	95	99	70	86	371
1958	27	85	92	96	77	377
Average	25	84	117	71	95	391

TABLE XI. Frequency of weir licensing in Saint John and Charlotte Counties during 1947 and 1958 inclusive.

Number of years	Saint John County	Grand Manan	West Isles	Charlotte West	Charlotte East	Total	
						no.	%
12	15	16	53	21	39	144	20.9
11	1	27	19	14	10	71	10.3
10	2	16	8	11	20	57	8.3
9	2	8	11	7	8	36	5.2
8	0	9	6	4	9	28	4.1
7	1	9	10	9	8	37	5.4
6	0	2	11	7	4	24	3.5
5	2	8	8	10	7	35	5.1
4	5	11	11	7	6	40	5.8
3	3	9	14	6	8	40	5.8
2	5	5	10	4	10	34	4.9
1	14	14	48	29	38	143	20.7
Total	50	134	209	129	167	689	100.0

Weir records were examined in relation to the proposed dams and showed that from 1947 to 1958 there were from 56 to 85 weirs licensed and built in the high pool each year. In the low pool the numbers varied from 9 to 21.

The weir fishery is most active from May to November and although no records of weir catches are available prior to 1957 a study of catches during May to November is instructive because most of the landings during these months were the result of weir catches. Table XII gives landings by years for Saint John County and for the 4 divisions of Charlotte County over the period

TABLE XII. Herring landings in Saint John County and districts of Charlotte County during the summer seasons 1947 to 1958. Landings in thousands of pounds. (Summer = May to November inclusive.)

Year	Saint John County	Grand Manan	West Isles	Charlotte West	Charlotte East	Total
1947	7,482	11,109	29,384	16,858	28,624	93,457
1948	3,076	33,427	10,636	12,306	12,724	72,169
1949	5,473	23,798	13,335	2,883	13,707	59,196
1950	12,102	32,407	17,537	11,738	25,525	99,309
1951	5,335	9,520	15,967	23,255	10,461	64,538
1952	3,985	19,848	9,470	27,997	9,138	70,438
1953	4,716	11,497	7,332	12,911	11,402	47,858
1954	6,932	42,000	4,040	11,839	2,677	67,488
1955	1,955	5,797	3,924	6,961	2,650	21,287
1956	1,573	12,701	10,624	5,091	6,211	36,200
1957	4,835	18,650	11,311	26,224	5,784	66,804
1958	5,713	11,974	2,208	9,865	6,948	36,708
Average	5,265	19,394	11,314	13,994	11,321	61,288
Percentage	8.6	31.6	18.5	22.8	18.5	100.0

1947 to 1958. Saint John County catches are usually small and Grand Manan catches usually large. For the whole Quoddy Region, which includes West Isles, Charlotte West and Charlotte East, the annual landings are quite similar. Within the Quoddy Region, however, there are enormous variations from year to year. In Charlotte West, for example, the catches varied from 2,900,000 to 28,000,000 lb.

Daily landing records by individual units of gear were obtained for 1957 and 1958 and the weir catches for these two years are presented in Table XIII. This table gives supporting evidence of the variations in herring landings. Total catches were nearly 3 times larger in 1957 than in 1958, and catches in the various districts were 5 or 6 times larger in one year than in the other.

The average landings per weir in each of the 4 statistical districts of Charlotte County are shown in Table XIV. The average catch per weir in Charlotte West, which is almost entirely the proposed high pool area, is, in general, about twice that in West Isles and Charlotte East (the area outside the proposed dams). The average catch per weir in Grand Manan is similar to that for Charlotte West.

TABLE XIII. Landings of herring caught by weirs in Charlotte and Saint John Counties in 1957 and 1958.

District	Landings		
	1957	1958	Average
	lb	*lb*	*lb*
Saint John	6,348,000	3,522,000	4,935,000
Grand Manan	16,351,000	6,051,000	11,201,000
West Isles	12,231,000	1,821,000	7,026,000
Charlotte West	33,429,000	6,724,000	20,077,000
Charlotte East	6,024,000	7,367,000	6,696,000
Totals	74,383,000	25,485,000	49,934,000

TABLE XIV. Average landings per weir in Charlotte County statistical districts for the period May to November inclusive, 1947–1958. Landings in thousands of pounds.

Year	Charlotte West			West Isles		
	Catch	Weirs built	Catch per weir	Catch	Weirs built	Catch per weir
1947	16,858	50	337.2	29,384	121	242.8
1948	12,306	53	232.2	10,636	132	80.6
1949	2,883	61	47.3	13,335	136	98.1
1950	11,738	66	177.8	17,537	123	142.6
1951	23,255	76	306.0	15,967	125	127.7
1952	27,997	59	474.5	9,470	116	81.6
1953	12,911	67	192.7	7,332	98	74.8
1954	11,839	70	169.1	4,040	95	42.5
1955	6,961	62	112.3	3,924	81	48.4
1956	5,091	57	89.3	10,624	75	141.7
1957	26,224	63	416.3	11,311	73	154.9
1958	9,865	67	147.2	2,208	64	34.5
Average	13,994	62.6	223.5	11,314	103.3	109.5
	Charlotte East			Grand Manan		
1947	28,624	102	280.6	11,109	33	336.6
1948	12,724	99	128.5	33,427	69	484.4
1949	13,707	96	142.8	23,798	85	280.0
1950	25,525	95	268.7	32,407	91	356.1
1951	10,461	94	111.3	9,520	93	102.4
1952	9,138	100	91.4	19,848	91	218.1
1953	11,402	77	148.1	11,497	83	138.5
1954	2,677	85	31.5	42,000	93	451.6
1955	2,650	75	35.3	5,797	85	68.2
1956	6,211	76	81.7	12,701	73	174.0
1957	5,784	68	85.1	18,650	73	255.5
1958	6,948	57	121.9	11,974	61	196.3
Average	11,321	85.3	132.7	19,394	77.5	250.2

In Figure 7 (from Parrish, 1958) and in Table XIV great variations in average herring catches from year to year and place to place are apparent. The average catch per weir in Charlotte West (inside Passamaquoddy Bay), for example, was more than 10 times larger in 1952 than in 1949.

It is unlikely that variations of such magnitude reflect variations in the overall abundance of herring since total landings in the Bay of Fundy are remarkably uniform. They may, however, reflect changes in distribution and hence in availability to the weir fishermen. No measure of market demand is available but it is known to be extremely variable too and may, at least in some seasons, have more effect on landings than does the availability of fish.

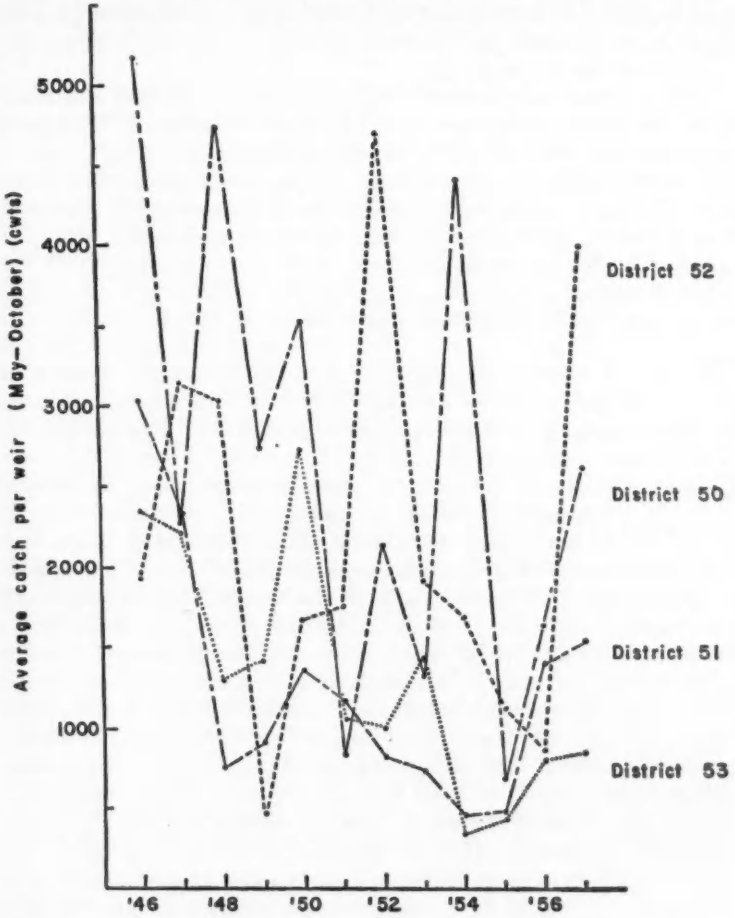

FIG. 7. Variations in weir catches, 1946–1957, calculated on basis of number of weirs licensed.

UTILIZATION OF CATCHES

In Canada, the small herring are used almost exclusively for canning as sardines, though 10 to 15% of the catch is used for bait, pet food and reduction to meal and oil. Large quantities of cuttings from the canneries are also used for reduction.

About half the herring caught in Charlotte and Saint John Counties are exported fresh to the United States, principally to Eastport and Lubec, Maine. In recent years most of the sales have been made to plants producing pearl essence and fish meal and oil. Other products include sardines, pet food, bait and smoked herring. In 1957 and 1958, about 60% of the exported herring were processed as pearl essence and fish meal, 20% as sardines, 19% as pet food, and 1% as bait and smoked herring.

In 1957, a year with above-average landings in Charlotte and Saint John Counties, the catch was utilized as follows: sardine canning 47%, pearl essence and fish meal 41%, pet food 11%, smoked herring and bait 1%.

For 1958, a year of below-average landings in Charlotte and Saint John Counties, the catch was utilized as follows: sardine canning 55%, pearl essence and fish meal 31%, pet food 7%, smoked herring and bait 7%.

SUMMARY AND CONCLUSIONS

The herring industry in southern New Brunswick is centered around Passamaquoddy Bay. Formerly the fishery was for large herring but from about 1880 to 1920 the large herring fishery declined to almost zero while a small herring fishery developed.

Torching and gill netting, the earliest methods of capture, have been supplanted by weir fishing, drag seining and purse seining.

Of the herring landings (217,000,000 lb, 1920–58 average) on the Canadian Atlantic coast including Newfoundland and Labrador, about one-third (78,000,000 lb) was made in the Bay of Fundy, 15% on the Nova Scotia side and 85% on the New Brunswick side. The New Brunswick landings increased from about 50,000,000 lb in 1920 to 110,000,000 in 1946 and then gradually declined to the 50,000,000 lb level. On the other hand the landings on the Nova Scotia side increased throughout the period from about 2,000,000 lb to nearly 40,000,000 lb.

On the New Brunswick side of the Bay of Fundy about 29% of the landings were made in Charlotte East, 27% in Grand Manan, 23% in West Isles, 15% in Charlotte West, and 6% in Saint John County (1937–58 averages).

The proposed Passamaquoddy tidal power dams will divide the area into a high pool (Passamaquoddy Bay), a low pool (Cobscook Bay, Lubec Channel, Friar Roads and part of Head Harbour Passage), and an outside area. During 1947–58, 18.8% (13,200,000 lb) of the Charlotte and Saint John County landings were made in the high pool, 1.1% (800,000 lb) in the low pool, 42.4% (29,800,000 lb) immediately outside and 37.7% (26,500,000 lb) in the remainder of the area.

In most of Charlotte and Saint John Counties about three-quarters of the landings were made from June to September. August was the peak landing month except in Charlotte West where largest landings were made in September.

Landings from torching and gill netting were insignificant. Drag seining, carried on chiefly in Charlotte West in September, accounted for 5.5% of the total catch in 1957 and 1958. Purse seining carried out chiefly in Charlotte East from January to April produced about 13% of the landings in 1957 and 1958. Of approximately 1,100 registered weir and shut-off sites in Charlotte and Saint John Counties, only 391 on the average (1947–58) were licensed annually. Weirs accounted for about 81% of the catch in 1957 and 1958. During 1947–58 about 32% of the weir catches were made in Grand Manan, 23% in Charlotte West, 18% in each of West Isles and Charlotte East and 9% in Saint John County.

In general the average yearly landings per weir in Passamaquoddy Bay (high pool) were much better than outside, the average for Charlotte West being 223,500 lb, for West Isles 109,500 lb and Charlotte East 132,700 lb. This indicates that the weirs in the proposed high pool are more efficient and suggests that Passamaquoddy Bay may act as a natural fish trap.

About half the herring caught in Charlotte and Saint John Counties are processed locally—almost exclusively canned as sardines—while the other half are exported to Maine where about 60% are processed as pearl essence and fish meal, 20% as sardines, 19% as pet food and 1% used for bait and for smoked herring.

ACKNOWLEDGMENTS

The authors wish to record their appreciation for assistance given during the course of this study. The benefit of B. B. Parrish's experience and advice as a consultant is gratefully acknowledged. Detailed records of herring catches for 1957 and 1958 were provided through the kindness and co-operation of Connors Bros. Ltd., Blacks Harbour, N.B., and H. W. Welch Ltd., Fairhaven, N.B. J. P. Wentworth of the U.S. Bureau of Commercial Fisheries provided records of herring exported to the United States. Canada Department of Fisheries officers including W. F. Doucet, K. E. Bates, F. Durant, G. Eldridge and M. Storr were especially helpful in supplying data on the licensing and operations of the various types of gear. Our thanks are also expressed to C. D. Burnett for organizing the great masses of records and for preparation of many of the tabulations.

REFERENCES

EARLL, R. E. 1887. The herring fishery and the sardine industry. The Fisheries and Fishery Industries of the United States, G. B. Goode *et al.* *U.S. Comm. Fish and Fisheries*, Sect. V, **1**: 417–524.

1889. Notes on certain fishery industries of Eastport, Maine in 1886. *Bull. U.S. Fish Comm.* for 1887, **7**: 267–274.

EARLL, R. E., AND H. M. SMITH. 1889. The American sardine industry in 1886. *Bull. U.S. Fish Comm.* for 1887, **7**: 161–192.

HUNTSMAN, A. G. 1948. Fishing and assessing populations. *Bull. Bingham Oceanographic Collection*, **9**(4): 5–31.

1953. Movements and decline of the large Quoddy herring. *J. Fish. Res. Bd. Canada*, **10**(1): 1–50.

MOORE, H. F. 1898. Observations on the herring and herring fisheries of the northeast coast, with special reference to the vicinity of Passamaquoddy Bay. *Rept. U.S. Fish Comm.*, **22**: 387–442.

PARRISH, B. B. MS, 1958. An appraisal of the Passamaquoddy herring problem. *Fish. Res. Bd. Canada, MS Rept.* No. 668, pp. 5–20.

PERLEY, M. H. 1852. Reports on the sea and river fisheries of New Brunswick. Queen's Printer, 294 pp.

SCATTERGOOD, L. W., AND S. N. TIBBO. 1959. The herring fishery of the Northwest Atlantic. *Bull. Fish. Res. Bd. Canada*, No. 121, 42 pp.

PLATE I. Distribution of herring landings in Charlotte and Saint John Counties, 1947.

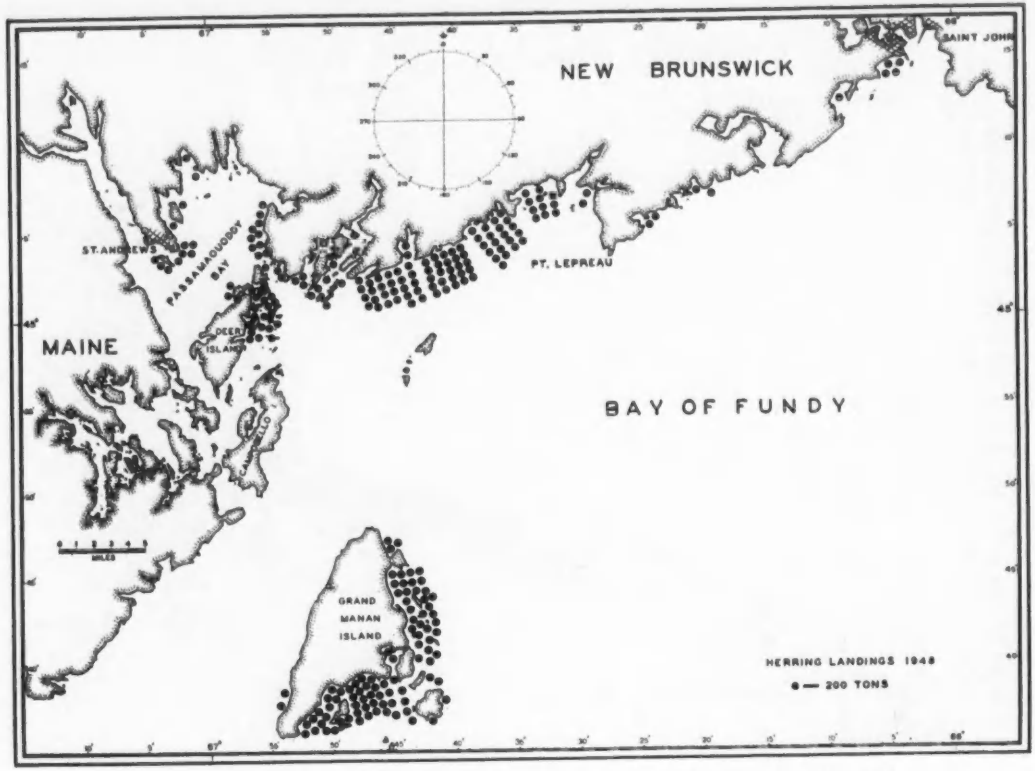

PLATE II. Distribution of herring landings in Charlotte and Saint John Counties, 1948.

PLATE II. Distribution of herring landings in Charlotte and Saint John Counties, 1948.

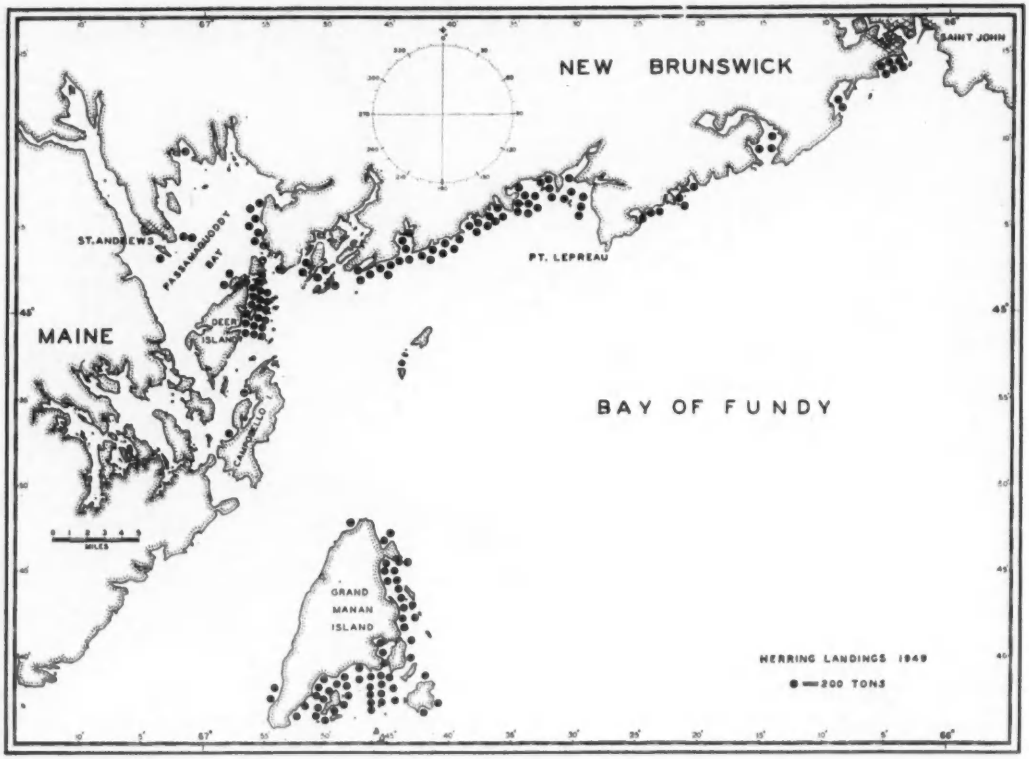

PLATE III. Distribution of herring landings in Charlotte and Saint John Counties, 1949.

PLATE IV. Distribution of herring landings in Charlotte and Saint John Counties, 1950.

PLATE IV. Distribution of herring landings in Charlotte and Saint John Counties, 1950.

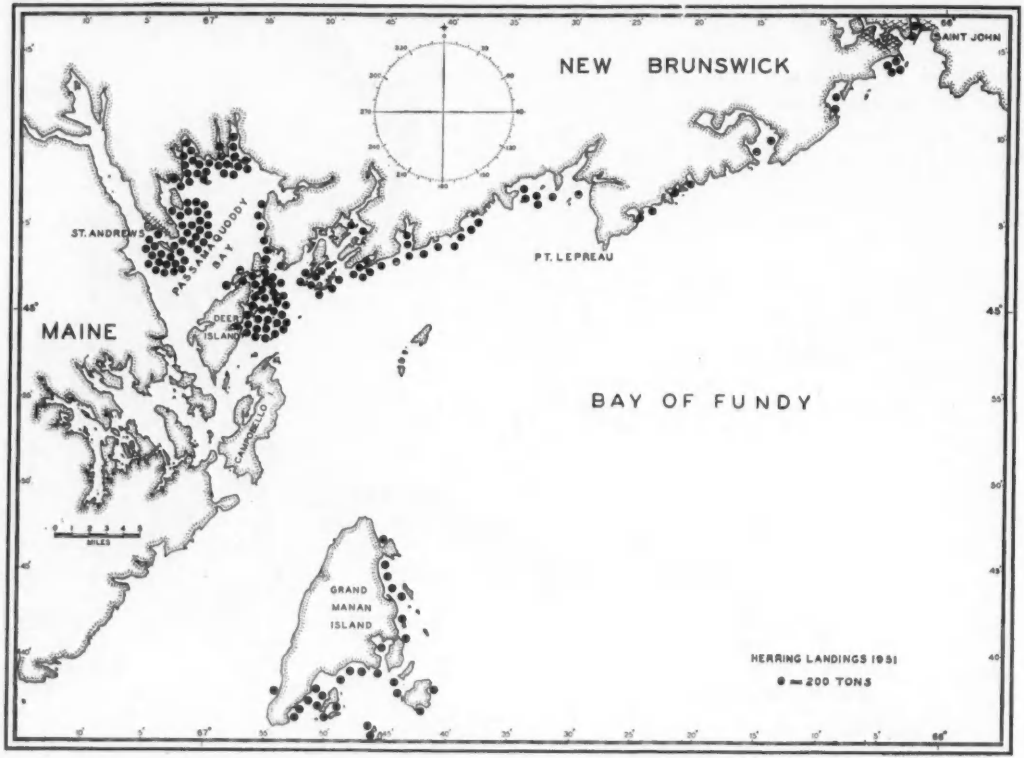

PLATE V. Distribution of herring landings in Charlotte and Saint John Counties, 1951.

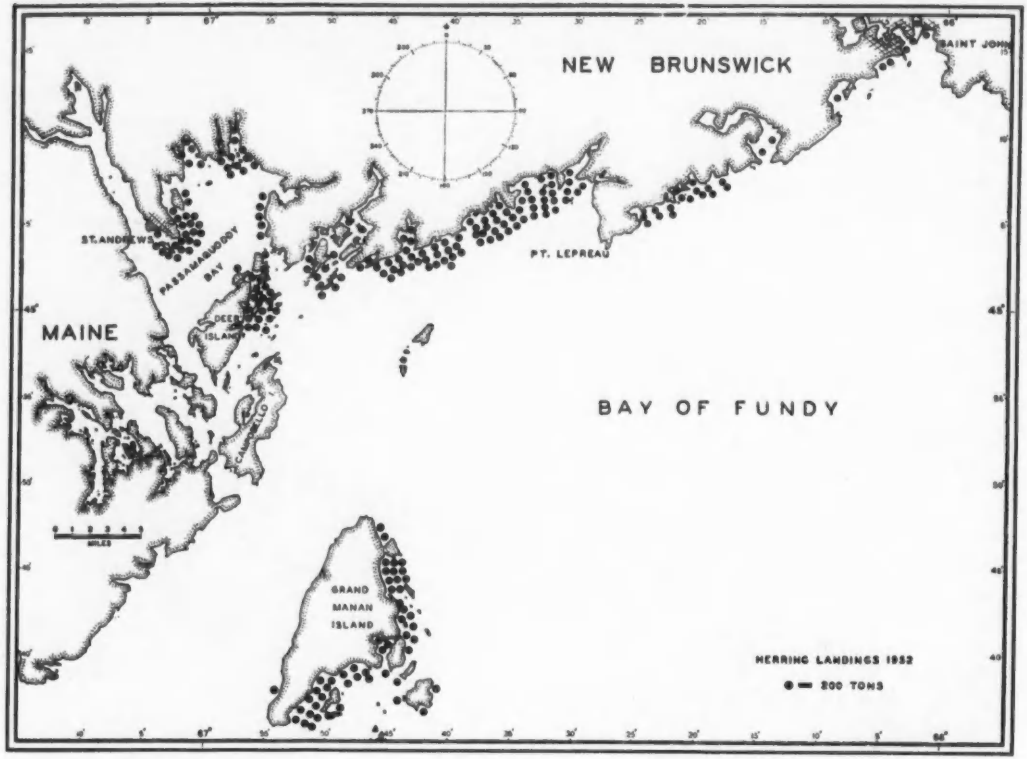

PLATE VI. Distribution of herring landings in Charlotte and Saint John Counties, 1952.

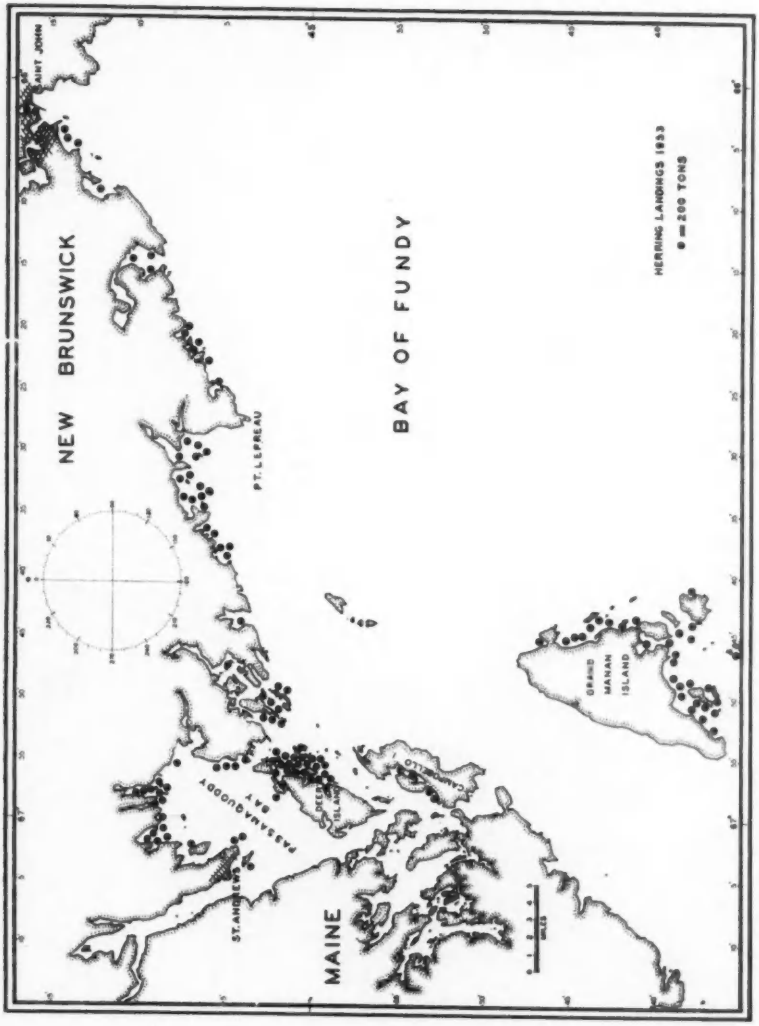

PLATE VII. Distribution of herring landings in Charlotte and Saint John Counties, 1953.

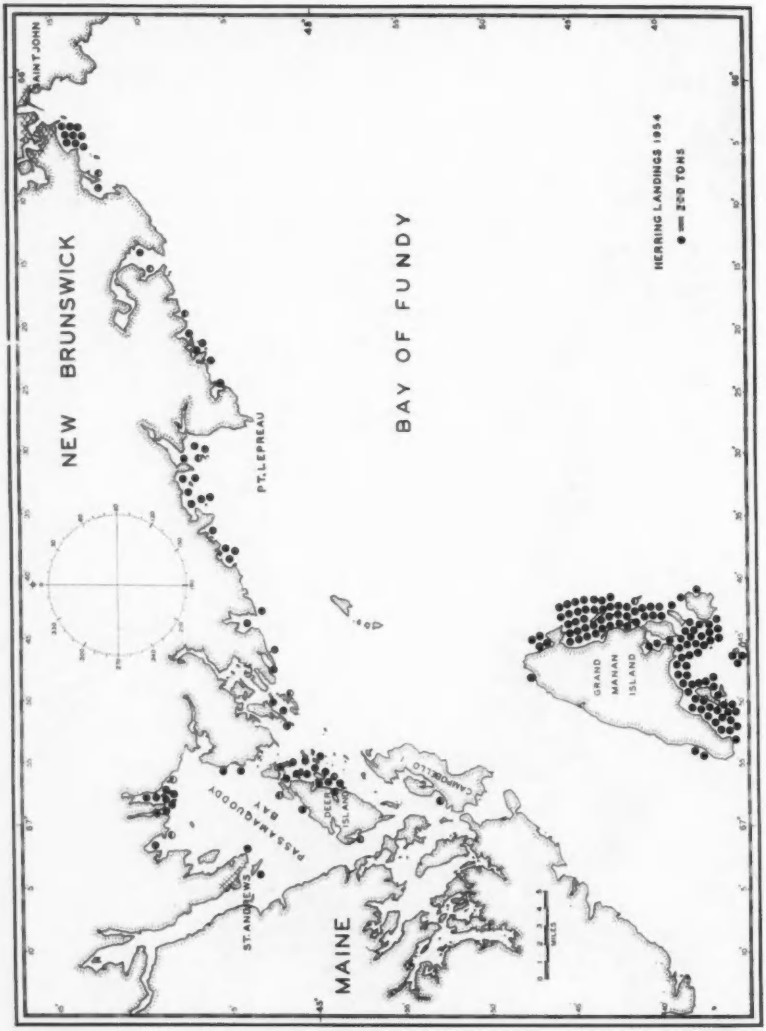

PLATE VIII. Distribution of herring landings in Charlotte and Saint John Counties, 1954.

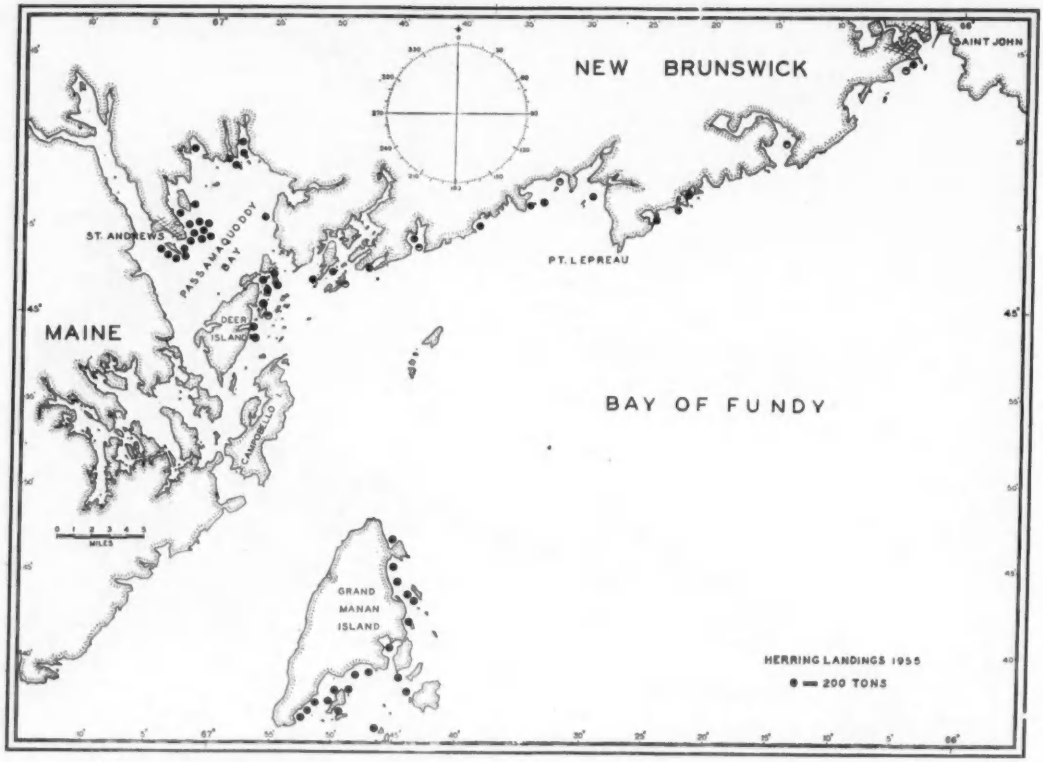

PLATE IX Distribution of herring landings in Charlotte and Saint John Counties, 1955.

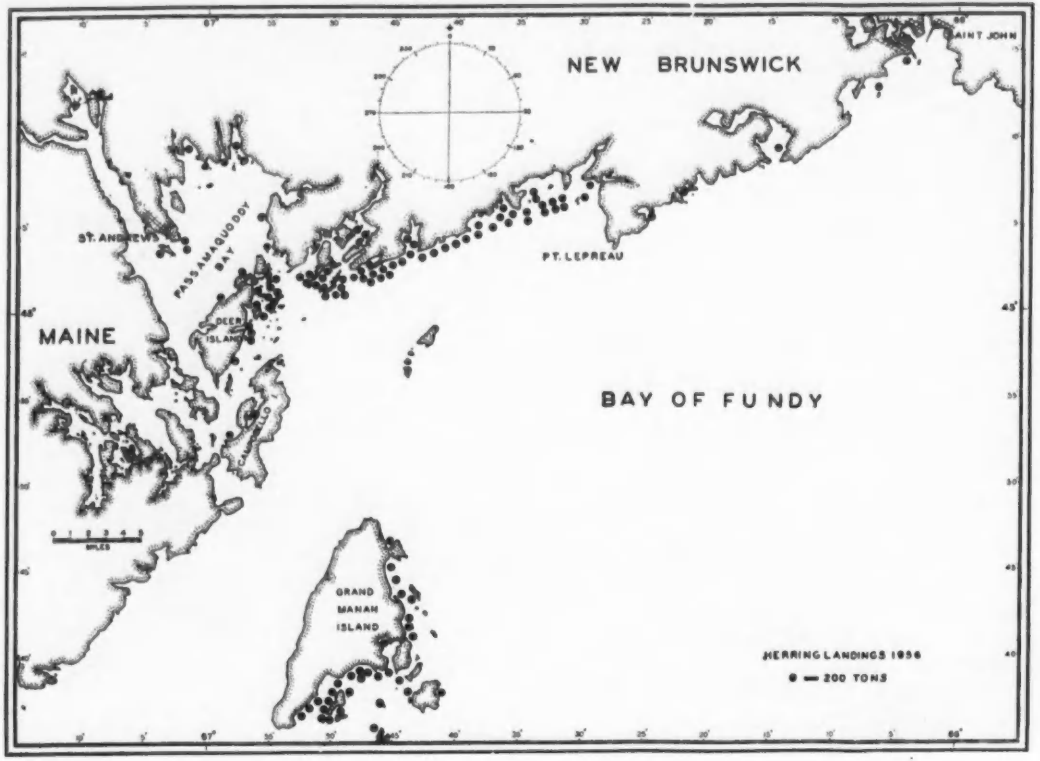

PLATE X. Distribution of herring landings in Charlotte and Saint John Counties, 1956.

PLATE X. Distribution of herring landings in Charlotte and Saint John Counties, 1956.

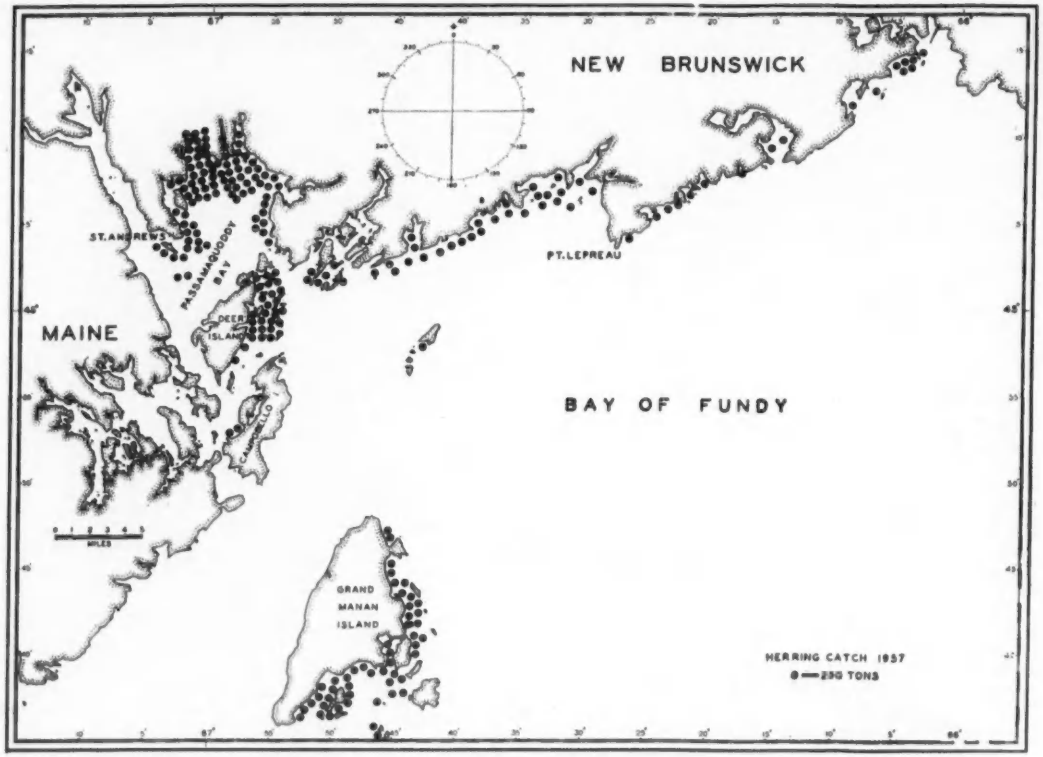

PLATE XI. Distribution of herring landings in Charlotte and Saint John Counties, 1957.

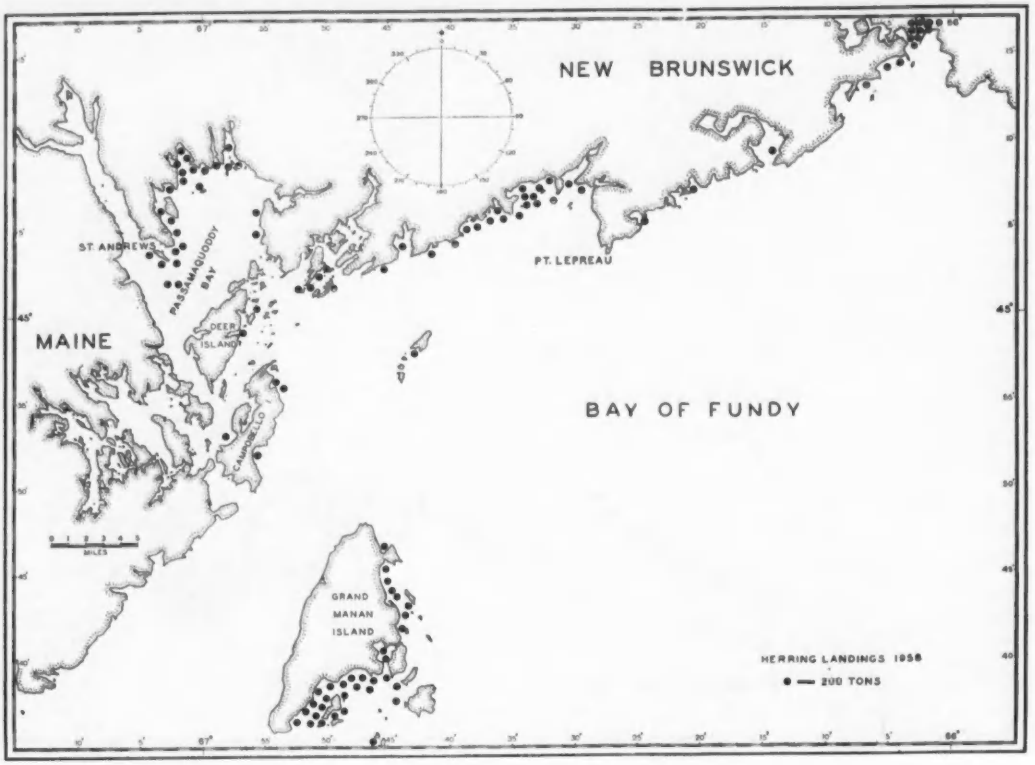

PLATE XII. Distribution of herring landings in Charlotte and Saint John Counties, 1958.

Predicted Effects of Proposed Tidal Power Structures on Groundfish Catches in Charlotte County, N.B.[1,2]

BY W. R. MARTIN

Fisheries Research Board of Canada
Biological Station, St. Andrews, N.B.

ABSTRACT

It is predicted that the construction of power structures will have no measurable effect on Charlotte County groundfish landings as a whole. It is expected that the 1,700,000 lb or 12% of the Charlotte County groundfish catch, taken in 1958 inside the dam sites, will be greatly reduced. Specifically, it is forecast that the pollock line fishery in Head Harbour Passage, which yielded 1,500,000 lb in 1958, will be greatly reduced, the haddock dragger fishery will be reduced or eliminated in the high pool, and the flounder fishery in Passamaquoddy and Cobscook Bays will probably increase.

INTRODUCTION

THE GROUNDFISH FISHERY of Charlotte County, New Brunswick, Canada, has been examined as a basis for prediction of the effect of the proposed Passamaquoddy power project on landings of groundfish species.

GROUNDFISH LANDINGS

The commercially important groundfish species have been pollock, *Pollachius virens* (L.), haddock, *Melanogrammus aeglefinus* (L.), cod, *Gadus callarias* (L.), hake, *Urophycis tenuis* (Mitch.), flounders, mainly the winter flounder, *Pseudopleuronectes americanus* (Walb.), and redfish, *Sebastes marinus* (L.).

Annual Charlotte County landings and landed values of these species are summarized in Table I. The statistics have been averaged by 5-year periods for the years 1937–1956. Landings of pollock, haddock, cod and hake have been converted from gutted weights, as normally recorded in Canadian statistics, to round weights by using a conversion factor of 1.2. In 1958, groundfish landings exceeded 14 million pounds with a landed value of $380,000. Pollock has always been the dominant species by weight, but haddock brings a better price and in some years its total landed value exceeds that of pollock.

Although changes in the abundance of groundfish species have had some effect on landings, the major fluctuations are related to changes in methods of capture and in marketing conditions. For example, the decreasing importance of cod and the increased landings of haddock have been caused by increasing

[1]Received for publication December 14, 1959.
[2]International Passamaquoddy Fisheries Board, 1956–59. Scientific Report No. 9.

J. FISH. RES. BD. CANADA, 17(2), 1960.
Printed in Canada.

water temperatures, but also by the conversion from line fishing to otter trawling and by the conversion from salt-fish to fresh- and frozen-fish marketing since World War II.

Landings for the year 1958 are described in Fig. 1. Groundfish landings

TABLE I. Charlotte County groundfish landings and landed values.

Species	1937–41 average	1942–46 average	1947–51 average	1952–56 average	1957	1958
LANDINGS—*in thousands of pounds round weight*						
Pollock	4,798	3,098	3,920	6,581	6,539	7,980
Haddock	1,108	964	1,328	2,656	1,945	3,000
Cod	2,224	1,570	1,871	1,719	1,210	1,677
Hake	1,778	536	1,006	3,002	1,571	1,284
Flounders	...	...	...	...	205	266
Redfish	...	...	3	37	...	3
Total	9,907	6,168	8,128	13,994	11,472	14,241
LANDED VALUE—*in hundreds of dollars*						
Pollock	203	837	549	1,026	1,505	1,404
Haddock	186	458	658	1,096	955	1,588
Cod	194	481	437	451	315	467
Hake	72	117	154	487	287	242
Flounders	...	...	...	...	74	91
Redfish	...	...	1	6	...	8
Total	655	1,894	1,799	3,066	3,136	3,801

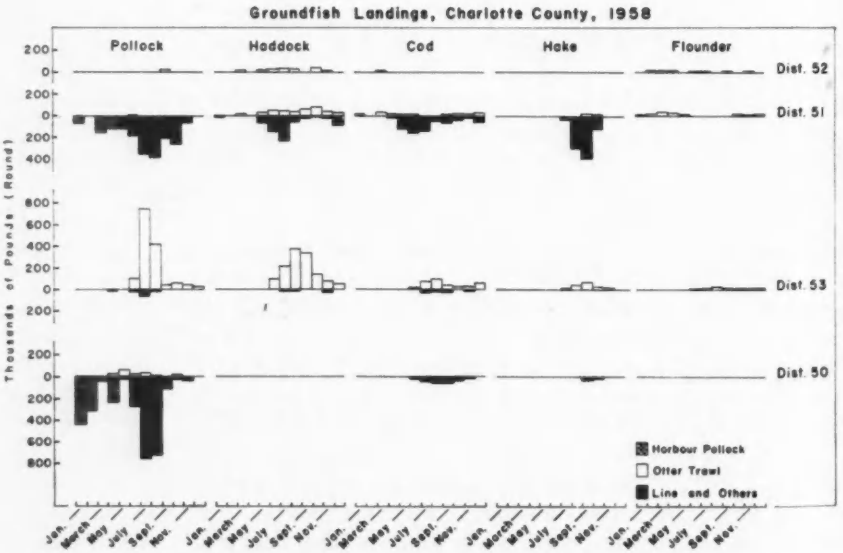

FIG. 1. Monthly landings for the year 1958 of groundfish (pollock, haddock, cod, hake, and flounders) in Charlotte County, New Brunswick (Statistical Districts 50 to 53) by gear fished.

in Statistical District 52, inside the dam sites, are of very little importance. The major species is haddock, and present landings are largely taken by one small dragger. Landings in District 51, Campobello and West Isles, make up a substantial proportion of the Charlotte County groundfish catch. Otter trawlers land some haddock and flounders, but most of the catch is still taken by line-fishing methods. Landings in District 53, Eastern Charlotte County, have become increasingly important with the opening, in 1958, of a fish plant at Beaver Harbour for fresh and frozen groundfish. Most of the fish are landed by 60-foot draggers. Although most of these draggers are based at Grand Manan, District 50, marketing facilities there are limited, and groundfish landings are mainly hook-and-line catches of pollock for salting.

Since World War II, purse seines, otter trawls, Norwegian jigs, and new methods of trolling have been introduced to the pollock fishery. Purse seines are used to catch small (harbour) pollock, mainly in the months of January to April. Otter trawls and lures take their best catches of large pollock during summer months.

DISTRIBUTION OF CATCHES

The distribution of groundfish landings is related to the areas in which the catches are made, and to the location of suitable wharves and fish buyers. Long-term statistics of groundfish catches by area fished are not available, but a survey was made for the year 1958 to assess current catches from the regions of the proposed high pool, low pool, outside the dams,[3] and from the Grand Manan area (Fig. 2).

The 1958 groundfish catch in the high-pool area was about 200,000 lb, and about 150,000 lb of this was haddock. The haddock catch represented part of the total annual landings of one dragger fishing on Perry Shore, Hardwood Island, Macmaster Island, and Clam Cove Head fishing grounds. Catches of cod, pollock, and winter flounder amounted to only about 20,000 lb each.

The groundfish catch from the low-pool area has been very small, except for an annual pollock catch of about 1,500,000 lb. These pollock are caught by small-boat, line fishermen in the Green Island Shoal area of Head Harbour Passage, just inside a proposed dam site.

The 1958 catch of groundfish from grounds just outside the dam sites was about 4,000,000 lb. Significant catches of pollock, haddock, cod, hake, and flounders were taken from Beaver Harbour, Wolves, Head Harbour, White Horse Island, Grand Manan Channel, and below Quoddy Head fishing grounds. Most of the catch was taken by line fishing, but important catches were also taken by seine net and by otter trawl.

[3]These terms refer to the proposed division of the Passamaquoddy region by hydro-electric power development—see Fig. 2 for their location.

The catch of groundfish from the Grand Manan area was about 8,000,000 lb in 1958. Pollock was the main species, but good catches of haddock and cod were also taken. Otter trawlers take most of the groundfish from inshore Gravelly and Soundings grounds and from offshore Grand Manan Bank. Line fishermen take their smaller share of the groundfish catch from inshore grounds.

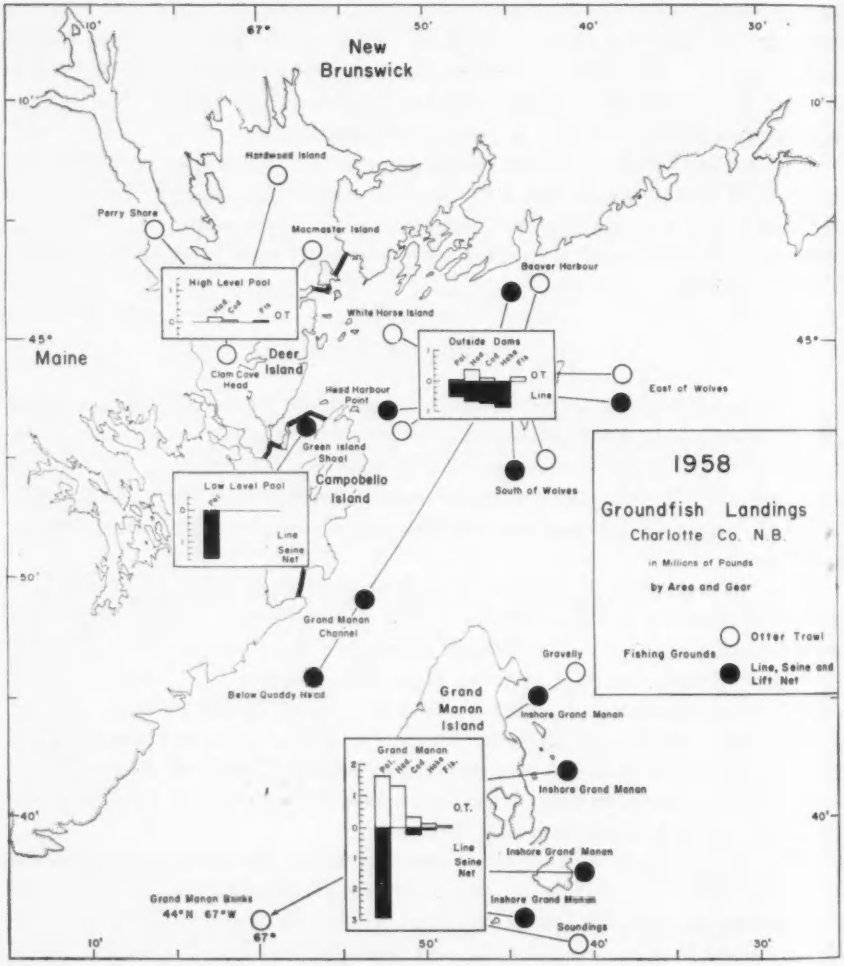

FIG. 2. Landings for the year 1958 of groundfish (pollock, haddock, cod, hake, and flounders) in Charlotte County, New Brunswick, by area (high pool, low pool, outside dams, and Grand Manan) and by gear fished (otter trawl, line, seine, and lift net).

PREDICTED EFFECTS OF POWER STRUCTURE

About 90% of the Charlotte County groundfish landings are caught outside the proposed Passamaquoddy dam sites. There is no reason to believe that this part of the catch would be measurably affected by construction of power dams. Fishing grounds immediately outside the dam sites might be altered, but the total catch should not be affected.

About 200,000 lb of groundfish, or about 1½% of the County groundfish catch, are now taken annually from the high-pool area. Three quarters of this catch is haddock. These haddock move in and out of Passamaquoddy Bay each year, as part of a New England stock (McCracken, 1960). The proposed dams are likely to reduce or even eliminate this annual migration in and out of the high-pool area. Since the haddock fishery inside the Bay is marginal now, with one dragger taking most of the annual catch, it is expected that the small, high-pool haddock fishery would be virtually eliminated with the construction of dams. The cod, pollock, and flounder fisheries of this high-pool area are very small, and it is anticipated that the total catch of these species will not change appreciably if dams are built.

The low-pool fishery for pollock would be greatly reduced by construction of power dams. The annual catch of about 1,500,000 lb of pollock from the Green Island Shoal area of Head Harbour Passage depends on a concentration of fish which are feeding on the shoals and in the eddies of this area. Although this local pollock fishery is expected to decrease, part of it will simply shift to other feeding grounds within the same general area.

Winter flounders should increase in numbers in high-pool and low-pool areas since anticipated conditions will more closely resemble those to the south where there are important winter flounder fisheries. A larger commercial and sport fishery for winter flounder is visualized.

REFERENCE

McCRACKEN, F. D. 1960. Studies of haddock in the Passamaquoddy Bay region. *J. Fish. Res. Bd. Canada*, 17(2): 175–180.

Studies of Haddock in the Passamaquoddy Bay Region[1,2]

By F. D. McCracken

Fisheries Research Board of Canada
Biological Station, St. Andrews, N.B.

ABSTRACT

From 1954 to 1957 haddock within Passamaquoddy Bay have been of intermediate sizes. Few small fish or large fish have been captured either by commercial fishermen or in small-mesh research nets. Tagged fish of the Passamaquoddy Bay region moved out of the Bay during winter and mingled mainly with haddock stocks off the New England States. In the following summer recaptures of tagged fish were again most numerous within Passamaquoddy Bay. Stocks of haddock within the Bay appear to result from annual migrations into the Bay in early summer. It is predicted that the proposed power structures would have no effect on haddock stocks outside the high and low pools but that they would probably seriously reduce the haddock population within the high pool.

INTRODUCTION

Accounts of brief studies of the life-history of haddock, *Melanogrammus aeglefinus* (L.), of Passamaquoddy Bay have been presented by Huntsman and Needler (1927) and Needler (1929, 1930). More recent haddock studies there have included sampling of Canadian landings for sizes, fishing for haddock with small-mesh nets, and haddock tagging. The results of these studies form a basis for prediction of the effects of proposed power structures on stocks of haddock in the vicinity of Passamaquoddy Bay.

RELATIONSHIP OF STOCKS

Sizes

Within and immediately outside Passamaquoddy Bay the fishery for haddock is seasonal in nature. Landings are greatest from May to December and much reduced from January to April (Martin, 1960). Sampling of the haddock stocks which have produced these landings has been carried out since 1954. Length distribution of haddock catches and landings from Passamaquoddy Bay during the autumn, October to December, for the period 1954–57 is shown in Fig. 1, Panel A. Catches from 1954–57 were made by a research vessel using an otter trawl with 40-foot headrope and codend covered with a 1½-inch stretched mesh cover. They include haddock smaller than those normally landed. The length

[1]Received for publication December 14, 1959.
[2]International Passamaquoddy Fisheries Board, 1956–1959. Scientific Report No. 10.

J. Fish. Res. Bd. Canada, 17(2), 1960.
Printed in Canada.

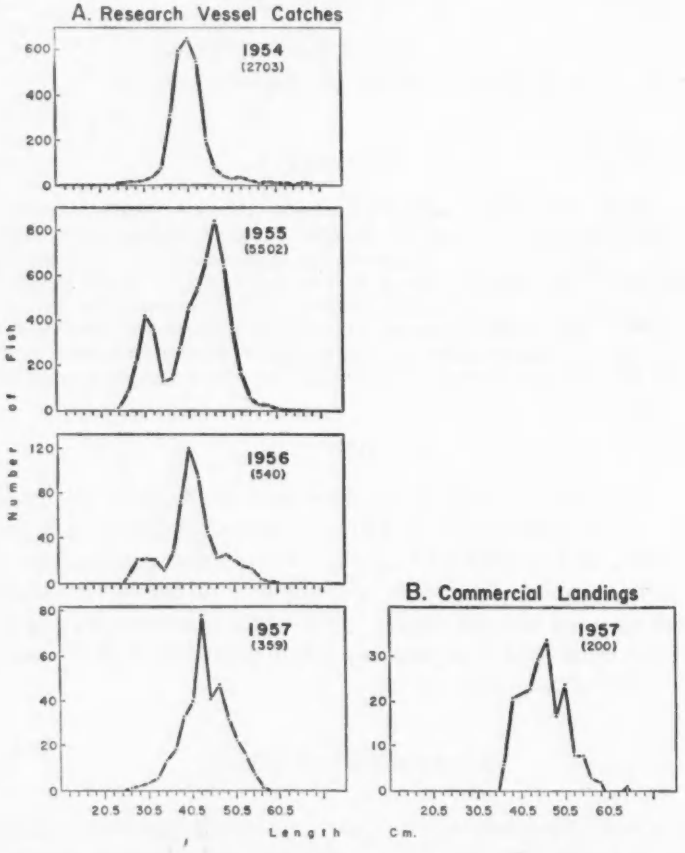

FIG. 1. Size composition of haddock from Passamaquoddy Bay during autumn, October to December. A. Catches by research vessel with a 1½-inch stretched mesh codend cover, 1954 through 1958. B. Landings by commercial trawler, 1957.

distribution of haddock in commercial landings for 1957 is shown in Fig. 1, Panel B.

Scrod haddock, 40–50 cm and about 1½–2½ lb, predominated in the research vessel catches. Virtually no fish below 30 cm in length were taken, but in 1955 and 1956 haddock around 30 cm in length were more numerous than in other years (Fig. 1). Only a few large haddock over 50 cm were taken in any year between 1954 and 1957.

A comparison of modal sizes suggests the progress of particular year-classes through the fishery. In 1954 haddock catches had a mode between 38 and 42 cm; in 1955 the mode was between 44 and 48 cm. Similarly, the group of fish around 30 cm in 1955 probably corresponded with the group around 38 to 42 cm in 1956.

Commercial vessels landed haddock down to about 35 cm but most fish were between 40 and 50 cm. Only a few larger fish (over 50 cm) were landed. The scarcity of larger fish was also recorded by Needler (1930) who concluded that haddock 5 years of age and over were seldom found in Passamaquoddy Bay.

Tagging

In November and December 1957, 1,085 haddock caught by otter trawl were tagged near the mouth of the Bay of Fundy. Of these, 508 were tagged and released in Passamaquoddy Bay, 507 in Grand Manan Channel, and 70 off Digby Neck on the eastern side of the Bay of Fundy. All were tagged with yellow Petersen disk tags, attached to the back of the fish by stainless steel wire.

The distribution of recaptures from these tagged fish is shown in Fig. 2. In November and December, immediately following tagging, haddock were recaptured close to the tagging region. Later in the "winter", December to May 1957–58, haddock tagged in Passamaquoddy Bay and Grand Manan Channel were widely distributed. Most "winter" recaptures came from the Gulf of Maine off Portland and Gloucester, in the vicinity of Jeffreys Ledge. An additional group of recaptures came from off the northwest edge of Georges Bank. In both these regions the majority of recaptures were made during February to April. About 15% of the distant recaptures of haddock tagged on the New Brunswick side of the Bay of Fundy were retaken during the winter of 1957–58 off southwestern Nova Scotia around Digby Neck and Browns Bank.

While only a few fish were tagged off Digby Neck, the returns complement the results from Passamaquoddy Bay tagging. Most of the Digby Neck tagged haddock recaptured during the following winter were taken around Browns Bank, but 2 fish were recaptured at Jeffreys Ledge off Gloucester, Mass.

In the "summer" following tagging, June to November 1958, most recaptures from haddock tagged on the western side of the Bay of Fundy were retaken in Passamaquoddy Bay. Only a few were retaken outside the Islands around the entrances to the Bay. Distant recaptures in "summer" included 3 from Georges

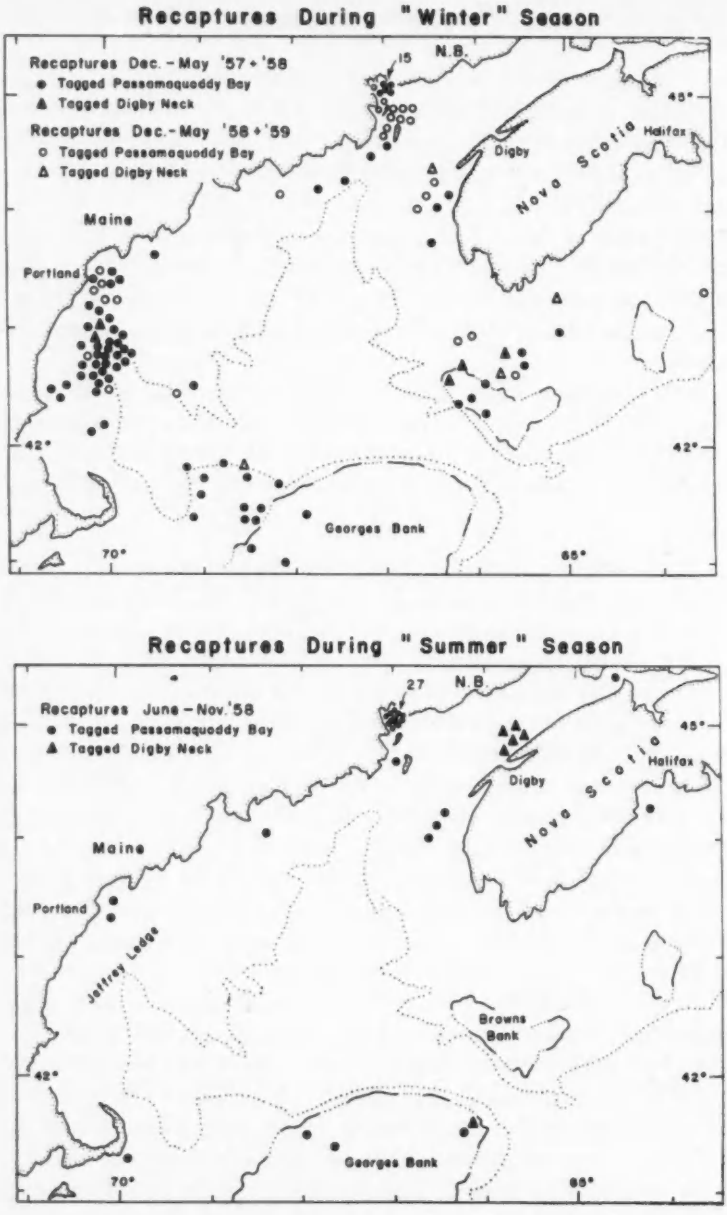

FIG. 2. Recaptures of haddock tagged in the Passamaquoddy Bay, N.B., region and off Digby Neck, N.S. (Figures record the number recaptured in Passamaquoddy Bay.)

Bank, 1 off Cape Cod, 2 off Portland, 4 within the Bay of Fundy, and 1 off St. Margaret Bay.

While tagged fish recaptures were considerably reduced in numbers during the second "winter" season (December to May 1958–59), the pattern of distribution of recaptures was only slightly changed. In December 1958, recaptures were greatest just outside the entrances to Passamaquoddy Bay, while later in the winter most recaptures were from New England and off Nova Scotia. The proportion of distant recaptures retaken off Nova Scotia in the second winter was much higher than in the first winter, 40% and 15%, respectively.

Conclusion

The evidence shows that Passamaquoddy Bay haddock are not produced by local spawning, since (1) the spawning season, March–April, corresponds with their southern migration and reduced abundance in the Bay, and (2) few small fish, under 30 cm, were taken within the Bay.

The combined evidence of tagging results, timing of commercial landings, and size compositions of haddock is interpreted to mean that haddock stocks within Passamaquoddy Bay are recruited each spring during a northward migration of fish along the coast of the Gulf of Maine and Bay of Fundy. Throughout the period studied, these recruits have been most important to the fishery as fish of scrod size, 40–50 cm in length. These fish summer within the Bay but leave in early winter to intermingle with haddock stocks in the Gulf of Maine. In addition, some fish cross the Bay of Fundy, and mix with haddock stocks off southwestern Nova Scotia.

FORECAST OF EFFECTS OF POWER STRUCTURES

From the statistics of landings in 1958 (Martin, 1960) it appears that the principal haddock stocks in the Charlotte County region are outside the proposed high and low pools. There is no evidence to suggest that these stocks would be materially affected by the construction of power dams.

Hydrographic conditions predicted within the high pool after construction of the power structures are not expected to be lethal for haddock. Thus, the crucial questions appear to be whether or not haddock would continue to move into the high pool, or, if not, whether an adequate resident population might develop. There is no clear cut answer to these questions. Presumably haddock will still be physically able to move into the high pool. However, in other areas of lowered salinity with narrow passages, such as Bras d'Or Lakes in Cape Breton, haddock are not present even though cod and flatfish are found. It also seems unlikely that the expected changes would influence haddock to begin extensive spawning within the high pool. It seems probable that haddock stocks within the high pool would be seriously reduced if not virtually eliminated.

REFERENCES

HUNTSMAN, A. G., AND A. W. H. NEEDLER. 1927. Fluctuations in the haddock fishery of the Bay of Fundy. *Contr. Canadian Biol. Fish.*, N.S., 3(18): 425–436.

MARTIN, W. R. 1960. Predicted effects of proposed tidal power structures on groundfish catches in Charlotte County, N.B. *J. Fish. Res. Bd. Canada*, 17(2): 169–173.

NEEDLER, A. W. H. 1929. Studies on the life-history of the haddock (*Melanogrammus aeglefinus* (L.)). *Contr. Canadian Biol. Fish.*, N. S., 4(20): 267–285.

1930. The migrations of haddock and the interrelationship of haddock populations in North American waters. *Ibid.*, 6(10): 243–313.

Sources of Water Contributed to the Bay of Fundy by Surface Circulation[1]

By Dean F. Bumpus[2,3]

Woods Hole Oceanographic Institution
Woods Hole, Mass., U.S.A.

ABSTRACT

The returns from the 35,000 drift bottles launched in the Gulf of Maine area since 1919 have been analyzed to determine the annual cycle of surface drift. The source of surface flow into the Bay of Fundy expands from a minimum during January in the offing of the eastern side of the bay to a maximum in May which includes most of Georges Bank, the Gulf of Maine and the southwestern Scotian Shelf, then commencing in September gradually contracts toward the minimum.

Secular variations in the removal of surface water from the Bay of Fundy, indicative of changes in the Maine eddy, were noted during 1957 and 1958.

INTRODUCTION

The circulation of water into an area, through it and out of it has much to do with the distribution of fishes in the area. Pelagic fish feeding at random may be effectively transported many scores of miles, particularly where they encounter non-tidal drifts of up to 10 miles (16 km) per day with no significant change in their environment to cause them to modify their random movements. The distribution of other fishes may result from the effects of non-tidal drift during the planktonic stages of their existence. Cod and haddock eggs float in the upper few meters of water for several weeks as do the larval cod and haddock hatched from these eggs. The resulting non-tidal drift during this period may disperse and remove this stock of fish from the spawning grounds to other places. Stormy winds for extended periods may be effective modifiers of the drift and may affect the survival of a year class (Chase, 1955). Herring larvae hatch from eggs adhering to the bottom and for several months thereafter are planktonic in the superficial waters. What are the current systems relative to the spawning grounds? How do these systems change with time? More specifically, do herring larvae spawned on Georges Bank during the autumn reach the Bay of Fundy?

The area under discussion and the names of places referred to in the text are indicated in Fig. 1.

[1]Received for publication October 20, 1959.
[2]Contribution No. 1086 from the Woods Hole Oceanographic Institution. This research was sponsored by the U.S. Fish and Wildlife Service under Contract No. 14–17–008–62.
[3]International Passamaquoddy Fisheries Board, 1956–1959. Scientific Report No. 11.

J. Fish. Res. Bd. Canada, 17(2), 1960.
Printed in Canada.

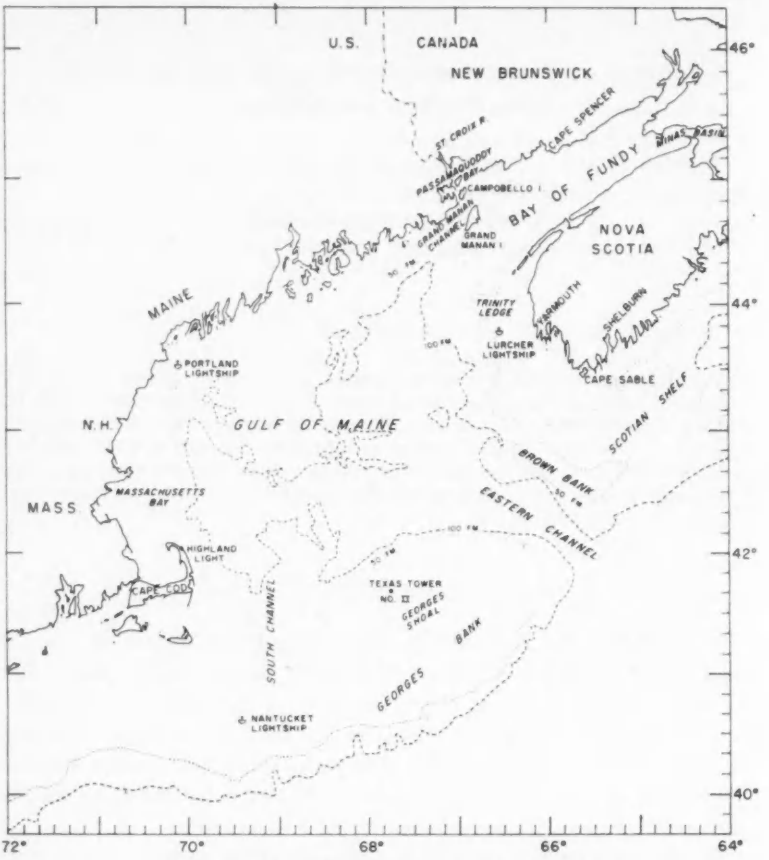

FIG. 1. Orientation chart of area under discussion.

PREVIOUS INVESTIGATIONS

Much of the information presently available stems from the results of international co-operation initiated by the North American Council on Fishery Investigations in 1922 and is discussed in detail by Bigelow (1927). Investigations have continued sporadically until the autumn of 1956 when co-operation between several laboratories in the United States and Canada was resumed.

CIRCULATION IN THE BAY OF FUNDY

Mavor (1922 and 1923) examined Dawson's (1908) current-meter data and his own drift-bottle experiments (June, August and September, 1919) together with the findings of Bigelow and concluded: " . . . that there is a movement of water into the Bay of Fundy from the Gulf of Maine and the southern end of the Nova Scotia coast and along the eastern side of the Bay of Fundy." This had been

surmised by Craigie and Chase (1918): "This movement is most marked at a depth of 50 meters but can be recognized from the surface to a depth of 100 meters. It extends into the Bay of Fundy on the Nova Scotian side at least 12 miles (19 km) below the Gulf of Digby. A portion of this water probably moves across the bay toward St. John Harbour." He also mentioned that there was a flow out of the bay to the east of Grand Manan and an inward movement in the Grand Manan Channel.

Returns from bottles set out by Huntsman in a line off Yarmouth, N.S., in July, August, September and October, 1926, (A.O.G., 1958) and summarized by Bigelow (1927) "demonstrate the northerly drift along western Nova Scotia into the southern side of the Bay of Fundy, and up it. The New Brunswick recoveries show the anti-clockwise movements brought out by Mavor's experiments."

Fish and Johnson (1937) set out several series of drift bottles in May and June 1932 in the northwestern part of the Gulf of Maine and in the southern part of the Bay of Fundy. They reported that numerous bottles from the northern part of the Gulf of Maine entered the Bay of Fundy. Many proceeded toward Minas Basin, others appeared to have followed the route suggested by Mavor and stranded in the Passamaquoddy Bay region or on Grand Manan. Those released in the Bay of Fundy gave similar results. There was also evidence that bottles released in the southwest portion of the bay proceeded across its mouth to the eastern side, suggesting a closed circulation at the surface at this time of the year.

Watson (1936) has described in detail the oceanographic observations made during 1932 and presents some dynamical evidence for the residual current systems mentioned above.

Hachey and Bailey (1952) report several drift-bottle experiments commenced in May 1930. They summarized their results as follows:

> "All of the drift bottles indicated a tendency of the waters to circulate the island of Grand Manan in a clockwise direction.
>
> "The movements of the bottles suggest a cyclonic circulation about the basin determined by the 50 fathoms (91 m) contour in the Bay of Fundy.
>
> "An intense movement towards the mouth of Passamaquoddy Bay is definitely illustrated, while it will be noted that the water movement along the coast of Campobello Island is outward.
>
> "An inward movement in the main waters between Grand Manan and the mainland is noted in keeping with the clockwise circulation about Grand Manan. However, the waters in contact with the coast of Maine have an outward movement."

Bumpus *et al.* (1957) launched radio drift buoys in the Trinity Ledge area off Yarmouth, in Grand Manan Channel and off Cape Spencer in the autumn of 1956. These experiments added some detail to the earlier descriptions of the circulation in the Bay of Fundy and confirmed the existence of the same general pattern for the autumn period. There were no previous drift experiments at this time of year in that region. The inflowing drift, restricted to the southeasterly side of the bay, averaged about 10 miles (16 km) per day, and the outflowing drift was restricted to the northwest side at comparable speeds. The inflowing drift was about 10 miles wide off Digby and the outflowing drift was about 6 miles (10 km) off Cape Spencer. While some of the water from the Lurcher Shoal–Trinity Ledge region may penetrate well up into the bay, perhaps

even to its head, cyclonic rotations with speeds of 2 to 4 miles (3 to 6 km) per day between the two drifts may shorten the route and allow transfer of water from one side of the bay to the other. These speeds are greater than those observed by the earlier investigators using drift bottles. Mavor (1922) and Fish and Johnson (1937) have tended to restrict the routes of drift bottles reaching New Brunswick to the vicinity of the 50-fathom (91-m) curve. We believe that the transfer from the inflowing to the outflowing drift can take place all along the centre portion well up into the bay.

The residual current in the Grand Manan Channel may be variable depending on the tidal range and meteorological condition (MacGregor and McLellan, 1952).

Circulation on the Southwestern Scotian Shelf

The circulation on the Scotian Shelf appears to be complex and variable. The efforts of the Canadian Fisheries Expedition of 1914–15, Bjerkan (1919), Huntsman (1924), Bigelow (1927) and Hachey (1947) reveal how complex the circulation may be.

A southwesterly flow along the Nova Scotia coast may prevail during the spring months, fed by the icy waters and ice flows debouching from the Gulf of St. Lawrence. This water may regularly be traced to the offing of Shelburne, and in some years on into the Gulf of Maine. This drift appears to cease by June at the latest. With the retrogression of the Nova Scotian current an eddy pattern may set up with cyclonic eddies about the basins and anticyclonic eddies about the banks. Hence inflow into the northern Gulf of Maine and the Bay of Fundy during the summer appears to be, not from the Nova Scotian current, which by this time has turned offshore and eastward off Shelburne, but from across Browns Bank. The area between Cape Sable and Shelburne evidently becomes a "dead area".

Only 3 of the 800 drift bottles released by Trites and Banks (1958) during August 1954 over the Scotian Shelf reached the Bay of Fundy. The circulation deduced from the bottle returns and distribution of salinity indicated a cyclonic circulation centered northeast of Sable Island. Only a narrow filament of the southwesterly drift, close to the shore, rounded Cape Sable into the Bay of Fundy.

Circulation in the Gulf of Maine

Bigelow (1927) has documented his many years of work in the Gulf of Maine in his extensive monograph on the "Physical Oceanography of the Gulf of Maine." The dominant non-tidal circulation comprises a cyclonic circulation in the Gulf of Maine and an anticyclonic circulation around Georges Bank and other shoals with seasonal and annual variations. Redfield (1939, 1941) has examined the time variation in the concentration of the pteropod *Limacina retroversa* and the crustacean plankton throughout the Gulf of Maine together with concurrent oceanographic data. He ascribed the principal factor influencing the distribution of these population densities to the inflow of water poor in these species from over the Nova Scotian banks in winter. The inflow is compensated by the escape of water to the south and east across the end of Georges Bank. The populations are able to grow and maintain themselves in the recurrent cyclonic

eddy which commences in the spring. Unfortunately Redfield's field work did not extend into the Bay of Fundy where the application of his theory would have been fruitful.

Day (1958) has examined the drift-bottle experiments conducted in the Gulf of Maine from 1931 to 1956 (Bumpus and Day, 1957) consisting of releases from late February through June.

Commencing in the autumn of 1956 drift-bottle experiments have been conducted in the Gulf of Maine on a nearly year-round basis. The results of Day's report and the still more recent experiments are summarized as follows:

Bigelow's (1927) July–August circulation pattern (Fig. 2), a relatively closed circulation and hence a highly conservative one, seems to be the climax of a seasonal evolution, possibly the result of vernal warming and river runoff and

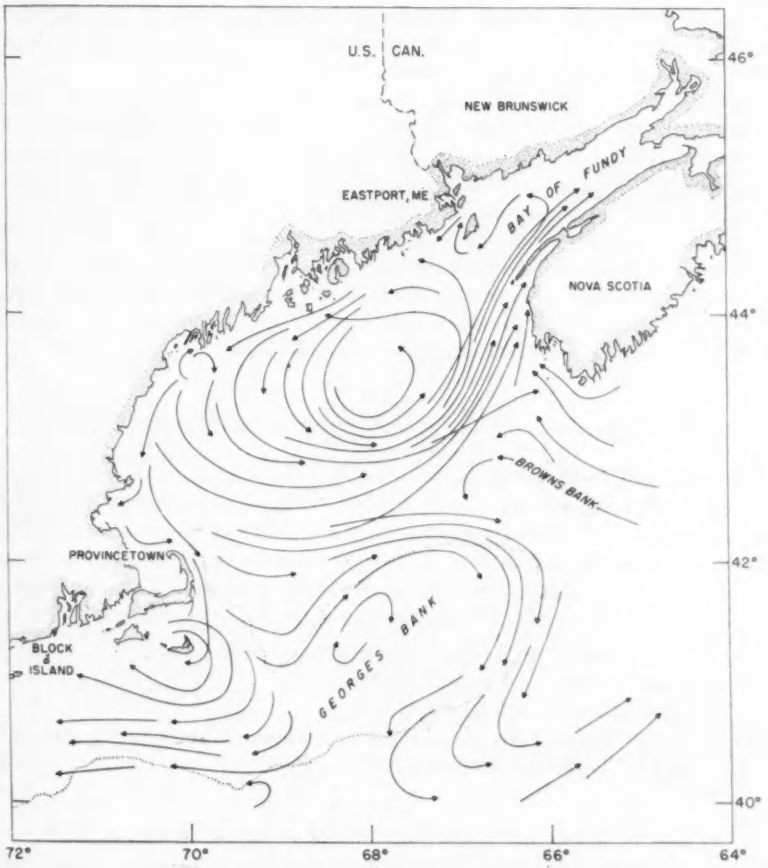

FIG. 2. Schematic representation of the dominant non-tidal circulation of the Gulf of Maine, July to August. (After Bigelow, 1927).

the consequent build-up of a dynamic structure conducive to the production of these motions.

In February and March, the Gulf of Maine eddy is ill defined on the south as water from Massachusetts Bay moves southward out South Channel. The Georges eddy is not apparent at this time, the net movement across Georges Bank being southwest. By late April, the two counter-rotating eddies are taking form with the appearance of a northeasterly movement along the northern edge of Georges Bank where the two eddies become confluent. A branch of the gulf eddy develops, penetrating into the eastern side of the Bay of Fundy. This dual eddy system continues throughout the summer. Beginning in September the Georges eddy breaks down as does the southern side of the gulf eddy. The indraft into the Bay of Fundy is limited to north of 43°, i.e. from over Eastern Channel and Browns Bank but not from Georges Bank. The western side of the gulf eddy weakens as winter sets in and the Georges eddy gives way by December to an easterly offshore drift. Just when this reverses to the southwesterly drift previously noted in February or March remains to be determined.

At any time during the year, the prevailing circulation may be modified by winds or river runoff. Offshore winds from the northwest quadrant have a pronounced effect on the Georges region tending to destroy the Georges eddy. Northeasterly winds, even of short duration, speed up the northern segment of the gulf eddy and increase the flow out South Channel. Winds from the west and southwest seem to give a strong onshore component to the waters south of Cape Cod and to accentuate the northward flow from Brown's Bank to the Bay of Fundy. A prolonged drought may weaken the western side of the gulf eddy, restricting the eddy to the northern half of the Gulf of Maine. Abundant river runoff will strengthen the western side of the gulf eddy.

COMBINED ANALYSIS OF ALL AVAILABLE DRIFT BOTTLE DATA

Over 35,000 drift bottles have been launched in the Gulf of Maine area over the 40-year period 1919 to December 1958, and more than 11% of them have been recovered. An attempt has been made to treat these data statistically. The number of bottles launched in each 30- by 30-minute rectangle of latitude and longitude by month, irrespective of year, has been recorded. Then the percentage of these bottles which reached the following shores has been determined, i.e.:

A. Southeast coast of Nova Scotia including Sable Island.
B. Eastern shore of the Bay of Fundy.
C. Western shore of the Bay of Fundy.
D. Coast of Maine, New Hampshire, and Massachusetts to Highland Light.
E. Highland Light southwestward.
F. Overseas.

The resulting tabulations have been plotted on charts (Bumpus, 1959) and the circulation deduced therefrom. The distribution of bottles released throughout the area is fairly good except for January, July, August and December. There is a paucity of data on the southwestern part of the Scotian Shelf except for south of Cape Sable.

Seasonal Progression

For the purposes of this paper two contours have been drawn for each month (Fig. 3). One contour encloses lightly shaded areas from which bottles have moved into the Bay of Fundy, limiting the "possible" sources of water which may reach the bay through surface circulation. The heavily shaded portions delineate the areas month by month from which 5% or more of the drift

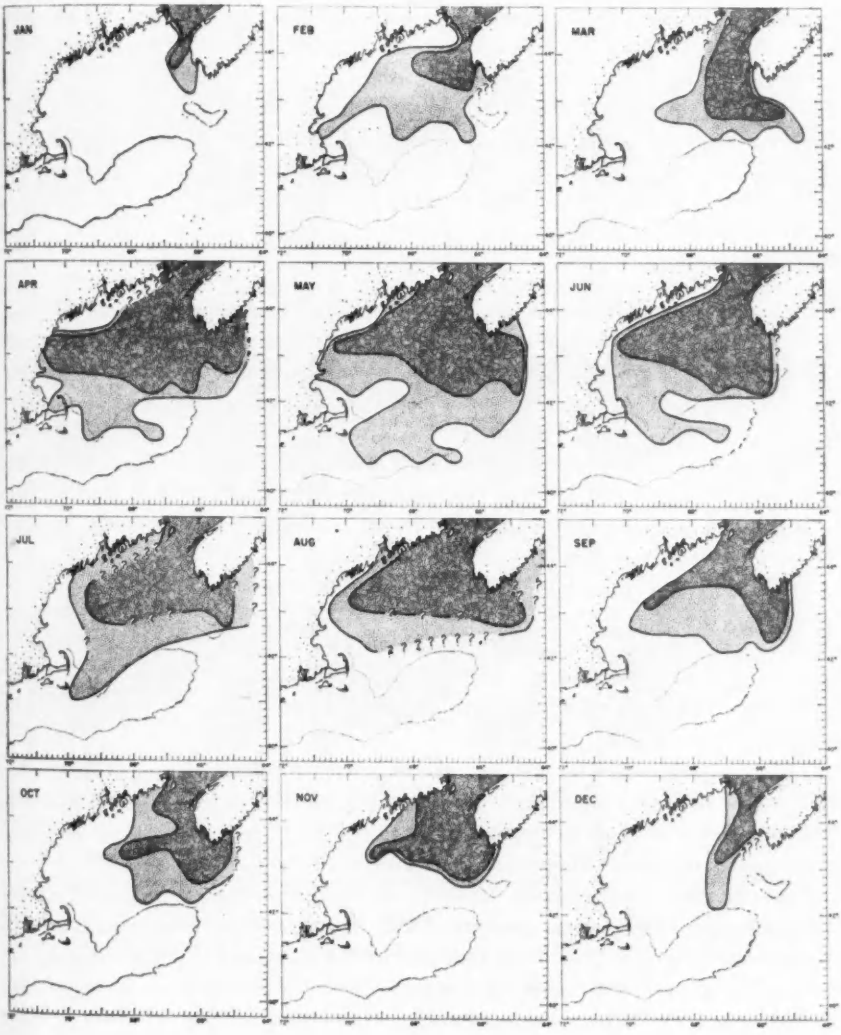

Fig. 3. Sources of water contributed to the Bay of Fundy by surface circulation. See text for explanation.

bottles have consistently reached the Bay of Fundy. These charts indicate a restricted source of surface drift into the bay in January, i.e. its southeastern approaches, gradually increasing during February and March parallel with the development of the Gulf of Maine eddy to a maximum during April, May and June, and concurrent with the development of the Georges eddy. Undoubtedly the source area continues near the maximum throughout July and August, but the drift bottle data for these two months are insufficient to delineate this, as indicated by question marks. By September the eddy systems have commenced to slow down with the consequent restriction in the area of water reaching the Bay of Fundy. The area is further withdrawn from Georges Bank during the autumn and early winter to the minimum in January. Note that the eastern boundary of the source area is annotated in some instances with question marks, indicating no data. Hence the Nova Scotian herring spawning ground may be within the limits of the Fundian circulation during the early autumn.

Secular Changes

Further demonstrations of the seasonal cycle in the southern part of the Bay of Fundy together with one spectacular secular change are available from the return of drift bottles launched at *Lurcher* Lightship and from those bottles launched during 1957 and 1958 which escaped from the Passamaquoddy Bay region.

The sequence of probable drift from *Lurcher* Lightship is indicated, month by month, in Fig. 4 and 5. The flow was generally either into St. Mary's Bay or slightly to the westward past Brier Island and thence northeasterly toward the head of the Bay of Fundy.

Following their release in May, June and July some bottles drifted across to the western side of the Bay of Fundy and so into Passamaquoddy Bay, much the same as has previously been observed by Mavor (1922) and Fish and Johnson (1937). We believe this to be characteristic of the summer circulation pattern.

During November 1957, the drift appeared to be directly to the Yarmouth area.

With regard to secular changes, the majority of bottles recovered following their release in January, February and March, 1958, had drifted to Massachusetts Bay with speeds as great as 8 miles (13 km) per day. This is in distinct contrast to the results observed subsequent to releases in January and March, 1957.

Bottles have been released regularly in large numbers in Passamaquoddy Bay and approaches since January 1957. Those which escaped from the Passamaquoddy region (Fig. 6 and 7) moved for the most part across to the western shore of Nova Scotia and thence northeasterly toward Minas Basin. A few bottles worked to the westward along the coast of Maine during May and June. This circulation continued, with minor variations, until December 1957; following

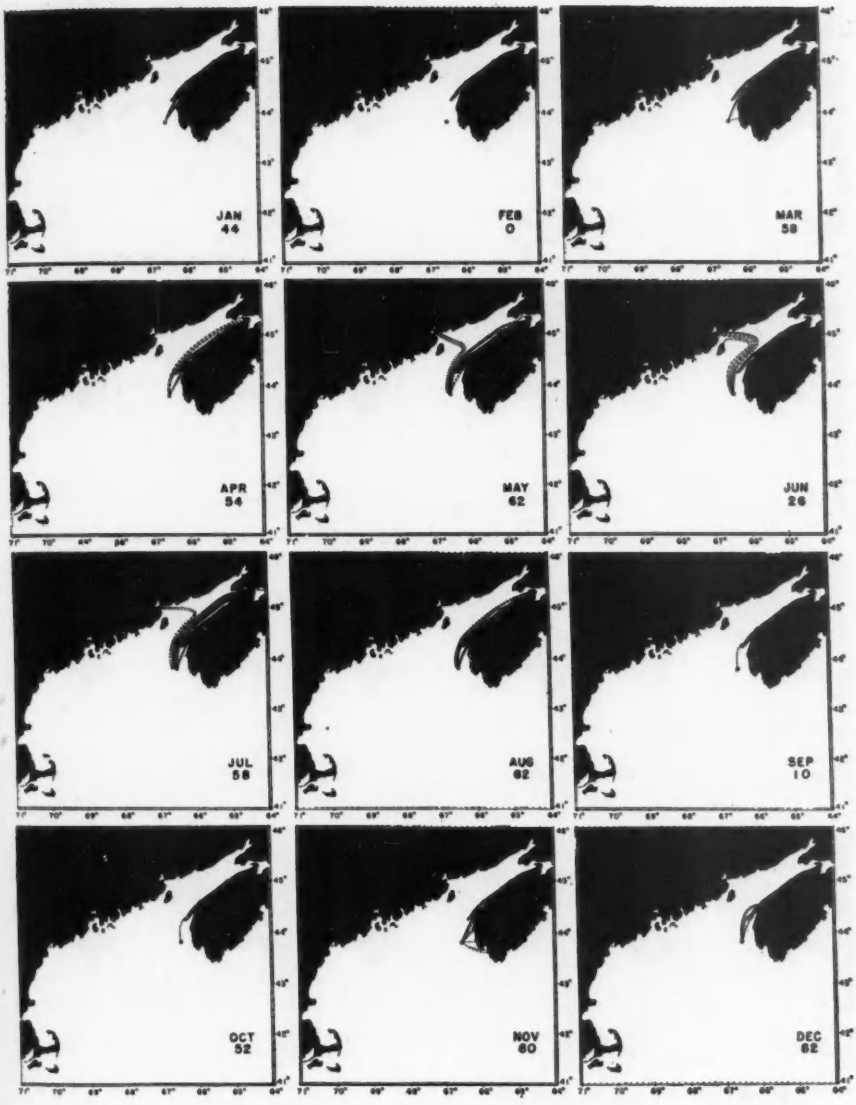

FIG. 4. Returns of drift bottles released at *Lurcher* Lightship during 1957. Number of bottles released each month indicated in lower right of each diagram.

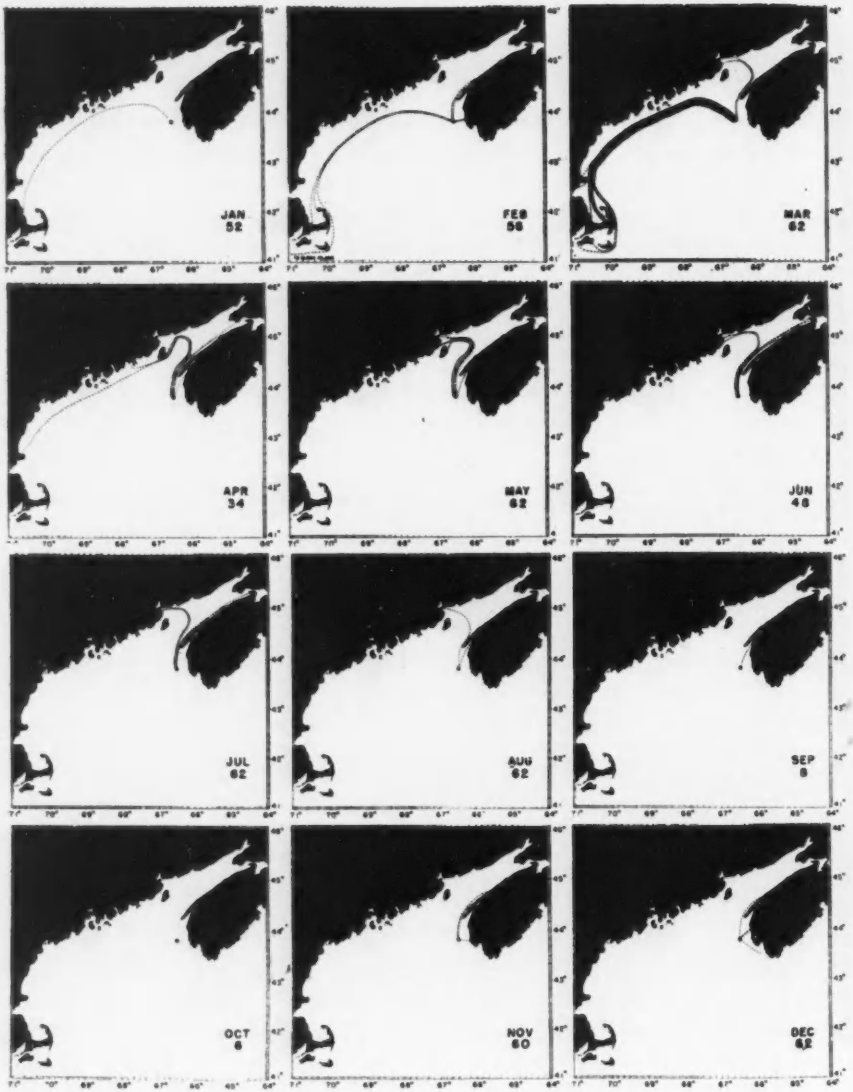

FIG. 5. Returns of drift bottles released at *Lurcher* Lightship during 1958. Number of bottles released each month indicated in lower right of each diagram.

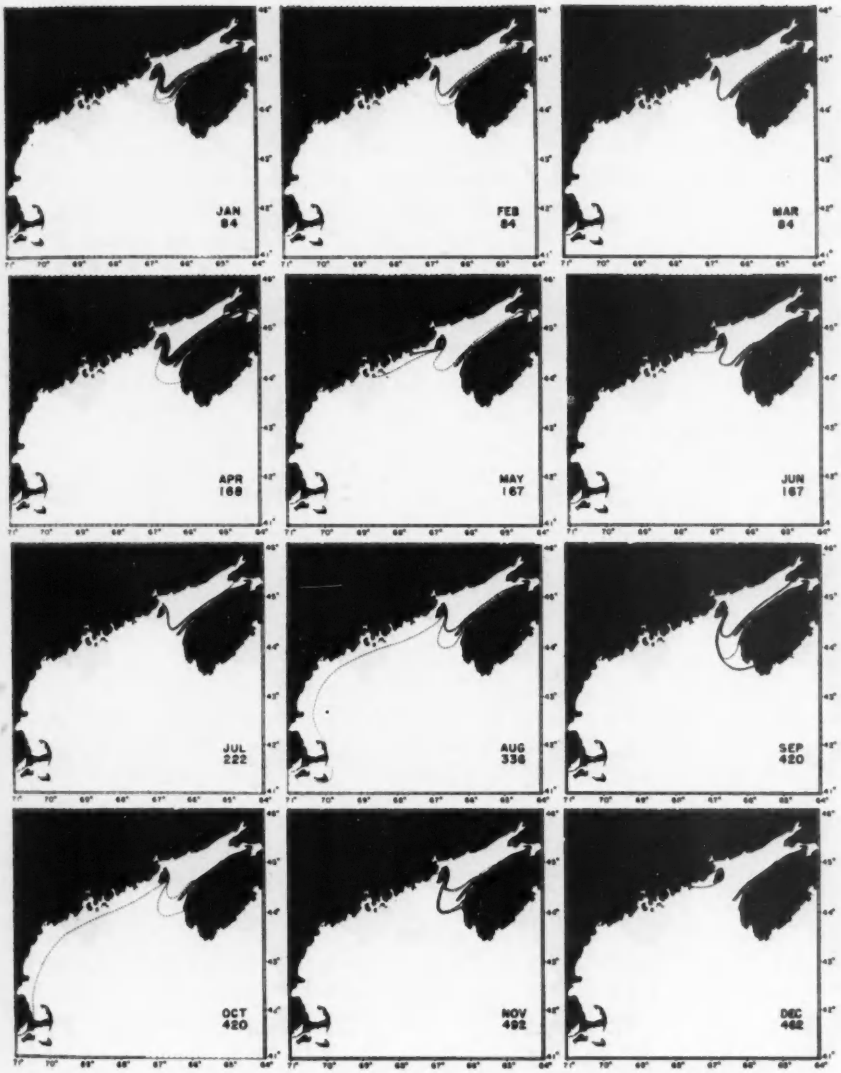

FIG. 6. Returns of drift bottles released during 1957 which escaped from the Passamaquoddy Area. Number of bottles released each month indicated in lower right of each diagram.

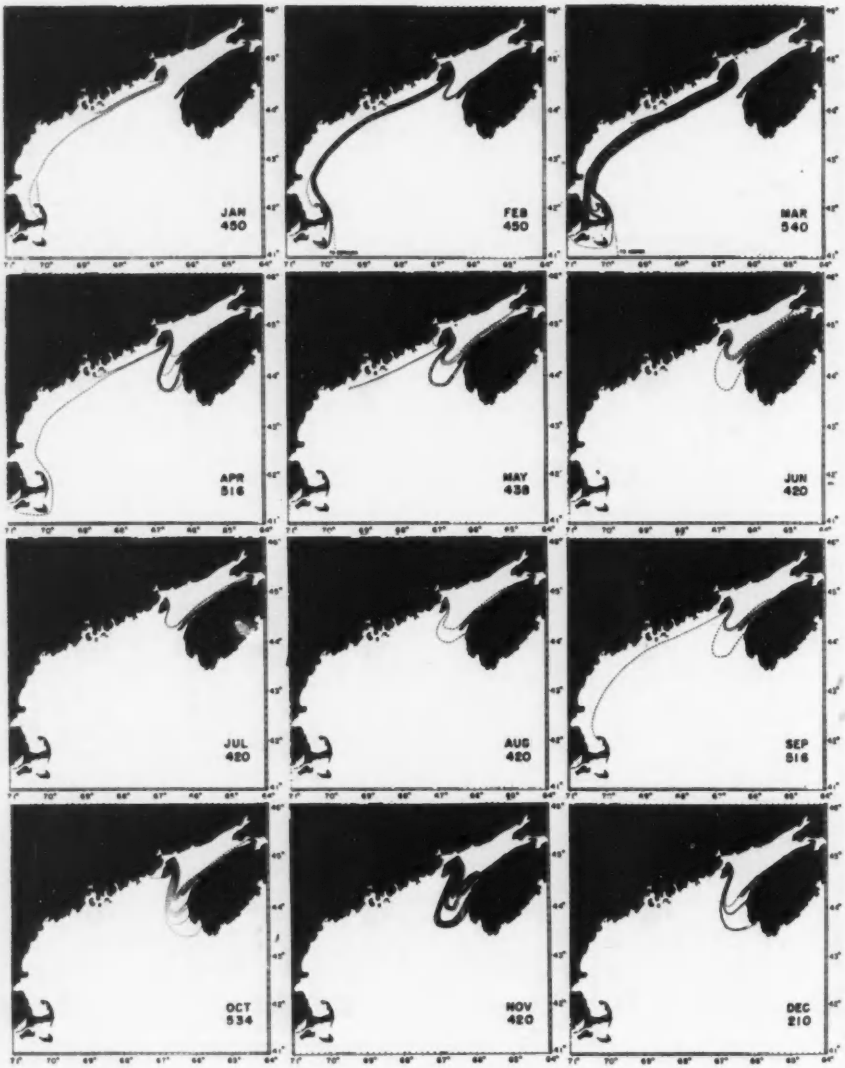

FIG. 7. Returns of drift bottles released during 1958 which escaped from the Passamaquoddy Area. Number of bottles released each month indicated in lower right of each diagram.

which time the set was toward the southwest, as evidenced by the stranding of bottles along the coast of Maine and ultimately Cape Cod. The usual drift across to Nova Scotia was resumed in April. These drift bottle returns are summarized in Table I.

There seems to be no doubt that there was a real difference in the circulation during the first three months of 1958 in contrast to the rather limited circulation during the first month of 1957. This is further substantiated by the releases from the fields of bottles launched in the Gulf of Maine immediately preceding or during these same periods.

TABLE I.

	Percentage of *Lurcher* Lightship bottles which went to:				Percentage of Passamaquoddy project bottles which went to:			
	Passamaquoddy Area	Grand Manan	Nova Scotia	Maine, Mass.	Passamaquoddy Area	Grand Manan	Nova Scotia	Maine, Mass.
1957								
Jan.	0	0	14	0	13.1	1.2	10.7	0
Feb.	...	...	...	...	28.6	0	3.6	0
Mar.	0	0	7	0	21.4	0	2.4	0
Apr.	0	0	13	0	20.2	0	7.7	0
May	5	0	11	0	31.1	0	0.6	1.8
June	15	4	4	0	44.9	1.2	1.2	1.2
July	3	0	14	0	50.0	0	1.4	0
Aug.	0	0	11	0	29.2	0.3	0.9	0.3
Sept.	0	0	10	0	22.2	0.7	1.0	0
Oct.	0	0	2	0	26.0	0.2	0.5	0.2
Nov.	0	0	13	0	27.0	0.4	1.4	0.2
Dec.	0	0	6	0	17.6	0.9	0	0.4
1958								
Jan.	0	0	0	2	14.4	0	0	1.1
Feb.	0	0	9	5	7.1	0.7	0.7	1.9
Mar.	0	0	3	18	17.8	0.4	0	3.7
Apr.	0	6	9	6	13.0	1.0	1.4	0.6
May	6	2	2	0	19.6	0.2	2.0	0.7
June	4	0	4	0	21.6	0.5	1.4	0
July	3	0	3	0	28.1	0.5	0.5	0
Aug.	2	0	2	0	27.2	0.5	0	0.2
Sept.	0	0	12	0	25.8	0.6	0.6	0.2
Oct.	0	0	0	0	22.5	0.6	1.7	0
Nov.	0	0	5	0	10.7	1.9	4.5	0
Dec.	0	0	5	0	8.0	0	1.9	0

DISCUSSION

The factors which may contribute to the non-tidal drift are:

a. The introduction of river runoff at the periphery of the area,

b. the dynamic pressure gradients resulting from unequal heating or cooling of the water over the area,

c. the frictional drag of the wind, and

d. the effect of the Coriolis force on tidal motions in restricted waters.

The runoff has an annual cycle on the average, but departures from the average are common in time and amplitude. The thermal cycle undergoes a regular annual progression. Departures from the mean are restricted to small changes in amplitude or time of occurrence. The wind systems likewise undergo a seasonal cycle but are subject to great departures from the mean in direction and force. Only the tidal motions are truly predictable. Huntsman (1924) has emphasized how the Coriolis force affects the tidal oscillations as an "imperfect valve" in producing stronger currents on the right side of the incoming flood into an embayment, and on the right side of the outgoing ebb. This effect results in a cyclonic eddy. Superimposed on this "Coriolis drift" are the seasonal effects of runoff and wind. The temperature effects are less easily demonstrated as secular effects and are probably less common and much less vigorous than the others.

Important wind effects in the Gulf of Maine have been detected (Day, 1958). Strong northerly winds of extended duration may accentuate the drift on the western side of the gulf or disrupt the southern side of the Maine eddy. One would expect such winds to have an impeding effect on any northerly directed drift. The runoff effect may be demonstrated by the returns from drift bottles launched at *Lurcher* Lightship and in Passamaquoddy Bay during January, February and March 1958 in contrast to the same time the previous year. The mean monthly discharge for the St. Croix River for December 1957 and January and February 1958 is substantially higher than for the same period a year before (Fig. 8); but more important, this higher-than-normal runoff occurred after 9 months of below-normal runoff, a condition common to the whole of the western side of the Gulf of Maine. The sea surface salinities were substantially higher than usual (*Albatross III* Cruise 106 data, 3–19 December 1957) as a result of the prolonged drought and resultant deficit in runoff from the land. The sudden increase in runoff commencing in December along the western side of the Gulf of Maine appears to have given impetus to the western side of the Gulf of Maine eddy at that time. This is further substantiated by the returns from bottles set adrift in the Gulf of Maine and Bay of Fundy in January and February 1958.

We are not able at this time to detail the normal sequence of circulation

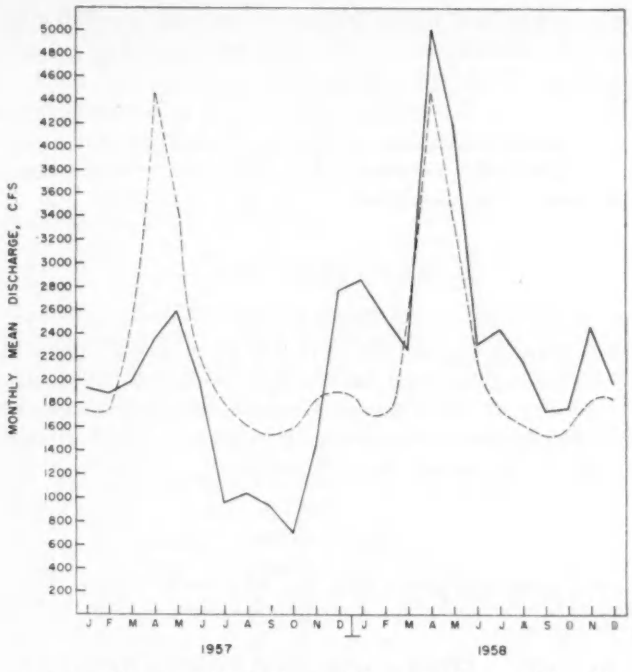

FIG. 8. Mean monthly discharge of St. Croix River at Baileyville for 1957 and 1958. Dashed line represents mean for period of record.

into the Bay of Fundy from east and south of Cape Sable. Bigelow's and Huntsman's data indicate that water from the Scotian Shelf does enter the Gulf of Maine during late spring. This appears to be an area where the current system is markedly unstable, moving into the gulf at one time but turning offshore at another. One might expect at least a slow drift from the inshore waters of southeastern Nova Scotia past Cape Sable at all seasons of the year, with a marked increase in speed and volume and distance offshore during the spring.

According to our present knowledge it would appear that herring spawned inshore on the Scotian Shelf during the autumn have a better chance of drifting into the Bay of Fundy than those spawned on Georges Bank.

SUMMARY

The surface circulation in the Bay of Fundy, Gulf of Maine and southwestern Scotian Shelf has been reviewed. The sources from which drift bottles have reached the Bay of Fundy have been demonstrated, outlining the month-by-month progression. The area from which drift bottles at the surface enter the

Bay of Fundy is restricted during January to the immediate approaches to the bay. It gradually expands during the spring to a maximum in early summer, encompassing most of the Gulf of Maine and part of Georges Bank as the result of the confluence of the Georges and Maine eddies. The source area gradually retracts during the autumn to the eastern side of the Gulf of Maine and northward away from Georges Bank. Some evidence of important secular departure from the normal circulation has been given.

ACKNOWLEDGMENTS

The author gratefully acknowledges the basic data collected over the years by the authors mentioned, together with the more recent efforts of the U.S. Bureau of Commercial Fisheries Laboratories at Woods Hole and Boothbay Harbor and workers at the Fisheries Research Board of Canada's Biological Station, St. Andrews, N.B., chiefly John B. Colton, Leslie Scattergood and S. Noel Tibbo, who have directed the field programs.

REFERENCES

A.O.G. (Atlantic Oceanographic Group, Fish. Res. Bd. Canada). MS, 1958. Canadian drift bottle data, Atlantic Coast. *Fish. Res. Bd. Canada, MS Rept. Series (Oceanog. and Limnol.)*, No. 15, 80 pp.

BIGELOW, H. B. 1927. Physical oceanography of the Gulf of Maine. *Bull. U.S. Bur. Fish.*, **40** (1924) Pt. II. Doc. No. 969: 511–1027.

BJERKAN, P. 1919. Results of the hydrographical observations made by Dr Johan Hjort in the Canadian Atlantic waters during the year 1915. Canadian Fisheries Expedition, 1914–15. Canada Department of Naval Service, pp. 349–403. Ottawa.

BUMPUS, D. F. MS, 1959. Investigations of climate and oceanographic factors influencing the environment of fish. Third Quarterly Report W.H.O.I., Ref. No. 59–10. (Unpublished.)

BUMPUS, D. F., J. CHASE, C. G. DAY, D. H. FRANTZ, JR, D. D. KETCHUM AND R. G. WALDEN. 1957. A new technique for studying non-tidal drift with results of experiments off Gay Head, Mass., and in the Bay of Fundy. *J. Fish Res. Bd. Canada*, **14**(6): 931–944.

BUMPUS, D. F., AND C. G. DAY. 1957. Drift bottle records for Gulf of Maine and Georges Bank, 1931–1956. U.S. Dept. of Int. Fish and Wildlife Serv. *Spec. Sci. Rept.–Fish.*, No. 242, 61 pp.

CHASE, J. 1955. Winds and temperatures in relation to the brood-strengths of Georges Bank haddock. *J. du Cons.*, **21**(1): 17–24.

CRAIGIE, E. H., AND W. H. CHASE. 1918. Further hydrographic investigations in the Bay of Fundy. *Contr. Canadian Biol.* (1917–1918), (7): 125–147.

DAWSON, W. B. 1908. Tables of the hourly direction and velocity of the currents and time of slack water in the Bay of Fundy and its approaches, as far as Cape Sable. Department of Marine and Fisheries, Canada, 15 pp. Ottawa.

DAY, C. G. 1958. Surface circulation in the Gulf of Maine as deduced from drift bottles. *Fishery Bull. of the U.S. Fish and Wildlife Serv.*, **58**(14): 445–472.

FISH, C. J., AND M. W. JOHNSON. 1937. The biology of the zooplankton population in the Bay of Fundy and Gulf of Maine with special reference to production and distribution. *J. Biol. Bd. Canada*, **3**(3): 189–322.

HACHEY, H. B. 1947. Water transports and current patterns for the Scotian Shelf. *J. Fish. Res. Bd. Canada*, **7**(1): 1–16.

HACHEY, H. B., AND W. B. BAILEY. MS, 1952. The general hydrography of the waters of the Bay of Fundy. Revision. *Fish. Res. Bd. Canada MS Rept. Biol. Sta.*, No. 455, 62 pp.

HUNTSMAN, A. G. 1924. Oceanography. Handbook of the British Association for the Advancement of Science, pp. 274–290. Toronto.

MACGREGOR, D. C., AND H. J. MCLELLAN. 1952. Current measurements in the Grand Manan Channel. *J. Fish. Res. Bd. Canada*, **9**(5): 213–222.

MAVOR, J. W. 1922. The circulation of the water in the Bay of Fundy. Pt. I. Introduction and drift bottle experiments. *Contr. Canadian Biol.* N.S., **1**(8): 101–124.

1923. The circulation of the water in the Bay of Fundy. Pt. II. The distribution of temperature, salinity and density in 1919, and the movements of the water which they indicate in the Bay of Fundy. *Ibid.*, **1**(18): 355–375.

REDFIELD, A. C. 1939. The history of a population of *Limacina retroversa* during its drift across the Gulf of Maine. *Biol. Bull.*, **76**(1): 26–47.

1941. The effect of the circulation of water on the distribution of the calanoid community in the Gulf of Maine. *Ibid.*, **80**(1): 26–110.

TRITES, R. W., AND R. E. BANKS. 1958. Circulation on the Scotian shelf as indicated by drift bottles. *J. Fish. Res. Bd. Canada*, **15**(1): 79–89.

WATSON, E. E. 1936. Mixing and residual currents in tidal waters as illustrated in the Bay of Fundy. *J. Biol. Bd. Canada*, **2**(2): 141–208.

Critical Size and Maximum Yield for Chinook Salmon (*Oncorhynchus tshawytscha*)[1,2]

By Robert R. Parker[3]

ABSTRACT

Instantaneous natural mortality rate is estimated from tagging and recovery data and compared with instantaneous relative growth rates for each life history type of chinook salmon. It is demonstrated that critical size is not attained prior to maturity, hence, juveniles should be protected from fishing if maximum yield in pounds is desired. Yield cannot be increased by a minimum size regulation, for losses due both to direct injury and hyperactivity reduce critical size to levels not ordinarily encountered by existing fisheries. A further complication arises in that size is not a reliable indicator of maturity. The most feasible alternative to a minimum size regulation appears to be spatial and temporal restriction of the fishery to known concentrations of maturing fish, together with the encouragement of non-size-selective gear.

INTRODUCTION

The theory of size limits has been discussed by Allen (1953, 1954), Ricker (1945, 1958) and by Beverton and Holt (1957), and applications of this theory by regulation to maximize the yield from various populations of fishes have been explored. The population models used, however, portray a structure in which a year-class, fully recruited to the fishable stock, is subject to an approximately constant natural mortality rate while growth rate is a declining function of age. It is shown that a *critical size* results from these two rates, defined by Ricker (1958, p. 209) as " . . . the size at which the instantaneous rates of growth and natural mortality are equal. At that time and size the year-class has its maximum bulk". Ricker (1945, 1958) presents arguments for maximizing yield by a *minimum size* regulation consistent with a given rate of fishing, where fishing starts prior to attainment of critical size, in lieu of the ability of a fishery to crop a year-class instantaneously.

Life history events of chinook salmon, however, exclude this species from such a simple model. Chinook are anadromous, and any particular race is widely distributed in the marine environment (Fry and Hughes, 1951; Kauffman, 1951; Milne, 1957; Neave, 1951; Parker and Kirkness, 1956; and others). During the immature stage some fraction of the population is susceptible to present fishing methods. Year-classes are recruited annually, thus fish of all ages and sizes may be present. With approaching maturity members of each particular race migrate from oceanic feeding grounds to the ancestral river and thus become increasingly concentrated and vulnerable to fishing, particularly by troll gear along migration

[1]Received for publication June 23, 1959.
[2]Contribution from the Alaska Department of Fish and Game, Juneau, Alaska, and from the Institute of Fisheries, University of British Columbia, Vancouver, Canada.
[3]Present address: Kitoi Bay Research Station, via Kodiak, Alaska.

J. Fish. Res. Bd. Canada, 17(2), 1960.
Printed in Canada.

routes and by gill net fisheries in the river estuaries or within the river itself. Individuals die after spawning and consequently do not re-enter the fishable stock.

Other features of chinook life history further complicate their population dynamics. Maturity may occur within any given year-class at several ages. For example, entering adult runs of Taku River chinook contained fish of ages 1+ to 5+ years (1 to 5 scale annuli) and of length groups from 10.0 to 47.5 inches (Anon., 1951). A size restriction, or gear restriction, designed to accomplish a maximum yield should consider the spawning loss of small but mature fish from the fishable stock.

A chinook year-class, then, at first is susceptible while immature to protracted fishing (both spatial and temporal) and finally to highly intensive fishing during a short period of approaching maturity. Each life history type is subject to natural mortality from disease, predation, etc., while immature, and then to complete mortality after spawning. Thus a population model must either consider life history types separately or include appropriate methods of weighting.

While all elements necessary to construct a population model are not at present known, certain questions can be discussed and answered from somewhat less complete information. Critical size for each life history type may be determined from natural mortality and growth rates, and, from knowledge of critical size, methods of fishing to produce maximum yield may be deduced. The determination of critical size and its application to determine biological management principles constitute the main objectives of this paper.

NATURAL MORTALITY

The rate of natural mortality[4] is perhaps the most elusive parameter to determine. A widely used approach is by the analysis of catch curves (Ricker, 1958), however the peculiarities of chinook life history and resulting population structure omit this method from consideration. It is, however, possible to compute natural mortality of a chinook population using data obtained from tagging.[5]

A population of N tagged fish is released during the year 0. As long as these fish remain immature they are subject to a negligible fishing rate. N_0, N_1, N_2, etc., denote the numbers of fish tagged belonging to groups which will mature during years 0, 1, 2, respectively, and R_0, R_1, R_2, etc., denote the numbers of tags recovered and turned in during the subscript years. It is necessary that the following assumptions be valid:

1. For any particular size category at time of tagging, the annual expectation of death from fishing (denoted by u) is constant during the years of the experiment.

[4]Natural mortality here refers to losses to the stock exclusive of those due to fishing and to death after spawning.

[5]This method was summarily published by the author (in Parker and Kirkness, 1956), but has been included in this paper in expanded form.

2. Annual mortality rate from natural causes (denoted by n) is constant, and natural survival rate, denoted by s, is equal to $1 - n$.

3. Rate of tag loss from structural failure does *not* progressively increase with time; though it may occur at a constant rate throughout the experiment, and if so, is included as a component of the apparent natural mortality, n.

4. The number of tags turned in each year is a constant fraction (denoted by r) of tagged fish recaptured.

5. Mortality due to tagging is complete within a short time after tagging; k denotes the fraction of fish surviving this mortality.

6. Natural mortality rate is the same for tagged and untagged fish.

The basic relationship between the tagged population and recovery of tags is defined by the equation:

$$R_i = N_i kru s^i \tag{1}$$

where i denotes any year of maturity after tagging. For the year of tagging (1) becomes:

$$R_0 = N_0 kru s^0 \tag{2}$$

and the survival term becomes 1. When the stock matures over a series of years:

$$\Sigma\left[N_i kru\right] = \Sigma\left[\frac{R_i}{s^i}\right] \tag{3}$$

and where tag recovery extends over j years:

$$Nkru = R_0 + \frac{R_1}{s^1} + \frac{R_2}{s^2} + \cdots \frac{R_j}{s^j} \tag{4}$$

also:

$$(Nkru - R_0)s^j = R_1 s^{(j-1)} + R_2 s^{(j-2)} + \cdots R_j s^0 \tag{5}$$

and:

$$(Nkru - R_0)s^j - R_1 s^{(j-1)} - R_2 s^{(j-2)} - \cdots Rj = 0 \tag{6}$$

The product kru can be estimated from the recovery during year 0 of fish known to be mature.

Appropriate data, presented by Parker and Kirkness (1956) from tagging studies conducted along the coast of southeastern Alaska, are:

$$\begin{aligned} N &= 918 \\ R_0 &= 110 \\ R_1 &= 35 \\ R_2 &= 11 \\ R_3 &= 1 \end{aligned}$$

kru was estimated from the recovery of fish tagged and released in their 5th and

6th years of life. From 215 of these fish tagged, 44 were recovered (42 during year 0). Thus for a first estimate,

$$kru = \frac{44}{215} = 0.205$$

and substituting the above data in equation (6) the relationship becomes:

$$[918(0.205) - 110]s^3 - 35s^2 - 11s - 1 = 0$$

$$78s^3 - 35s^2 - 11s - 1 = 0$$

the approximate solution of which gives: $s = 0.681$.

Since not all the 4+ and 5+ year old fish were mature, further consideration of *kru* is necessary. Following above reasoning, from (4):

$$kru = \frac{1}{N}\left(\frac{R_1}{s} + R_0\right)$$

and

$$kru = \frac{1}{215}\left(\frac{2}{0.681} + 42\right) = 0.209$$

This value is substituted into equation (6) and the second approximation of s is: $s = 0.659$. Further iteration does not affect the third decimal place of s.

The problem of variance of s has not been considered. A difference of one unit in the second decimal place of *kru* causes a change of approximately 5 units in the second decimal place of s; thus s is critically affected by error in estimating *kru*.

The assumptions given are also not completely satisfied. A small number of fish tagged were recaptured while yet immature. Fishing mortality rate may vary from year to year. Annual natural mortality rate may not be constant for all ages and/or sizes. No evidence of progressive change in rate of tag loss has been found in the Alaskan experiment, yet Calhoun *et al.* (1951) report high incidence of progressive tag failure (the same Petersen type tags were used) in the California studies. As was shown by Parker and Black (1959), Parker, Black and Larkin (1959), and from observations by Milne and Ball (1956, 1958) mortality from tagging would appear to be over or negligible within a few days after tagging. Perhaps the most critical assumption is that tagged fish are representative of the untagged population.

It is, at present, impossible to establish the validity of all necessary assumptions, however they appear to be reasonably satisfied in the population of chinook studied (Parker and Kirkness, 1956). Because of this deficiency no significance is placed beyond the first decimal place. The best available estimate of annual natural mortality rate is then given as in the magnitude of 0.3 to 0.4. Instantaneous natural mortality rate (denoted by q) is estimated to be of the magnitude 0.36 to 0.51.

SIZE SPECIFIC INSTANTANEOUS RELATIVE GROWTH RATE

It now becomes necessary to express instantaneous relative growth as a function of length. This can be done in the manner presented by Larkin *et al.* (1957) except in the present case growth in weight is desired. Accordingly, length data for age 1, 2, etc. are converted to weights using an appropriate weight–length relationship. From successive weights for each fish, instantaneous relative growth rates $\frac{dW}{Wdt} = \Delta \ln (W)$ are calculated, grouped according to initial length classifications, and averaged. The resulting averages are plotted as a function of length and a curve may be drawn freehand through the plot for a fair approximation.

Alternatively, the actual shape of the curve may be derived by the following theoretical treatment.

For any particular life history group the average size-specific annual growth rate (length) is described by the equation (Parker and Larkin, 1959):

$$l_{t+1}^z = a + l_t^z \tag{7}$$

where:

l denotes fork length;

z is an exponent and $z = y(1-x)$

where y is the exponent of the length–weight relationship and x defines the relationship between growth rate and size, i.e. $\frac{dw}{dt} = kw^x$;

a denotes the constant $\frac{k(1-x)^r}{q^{(1-x)}}$ and is an abstract unit expressing annual growth in length when length is taken to the power z;

t denotes time.

The weight–length expression:

$$w = ql^y \tag{8}$$

also defines l as a function of w, thus:

$$l = \left(\frac{w}{q}\right)^{\frac{1}{y}} \tag{9}$$

Substituting (9) into (7):

$$\left[\frac{w_{t+1}}{q}\right]^{\frac{z}{y}} = a + l_t^z ,$$

$$w_{t+1}^{\frac{z}{y}} = q^{\frac{z}{y}} \left(a + l_t^z\right) ,$$

$$w_{t+1} = q \left(a + l_t^z\right)^{\frac{y}{z}} \tag{10}$$

For a specific size subclass (any arbitrary length frequency group) of a life history group, the annual instantaneous relative growth rate (denoted by g) is:

$$g = \ln\left(\frac{w_{t+1}}{w_t}\right) \tag{11}$$

and:

$$g = \ln\left(\frac{q\,(a + l_t^z)^{\frac{y}{z}}}{q l_t^y}\right)$$

or:

$$g = \frac{y}{z}\left[\ln(a + l_t^z)\right] - y\left[\ln l_t\right] \tag{12}$$

Thus g is a function of y, z, a and l_t. Since y, z, and a are constants at any size during a particular physiological growth stanza within a particular life history group, g is a function of l_t, i.e., the relationship is a "size-specific instantaneous relative growth rate" in the sense proposed by Larkin, Terpenning and Parker (1957).

Average size at the ultimate annulus, mean a and the confidence interval of a for each life history type of chinook are presented in Table I[6]. Table II

[6]Based on data presented by Parker and Larkin (1959, Tables IV and V).

TABLE I. Average size at ultimate annulus, mean a ($z = 1.3$) and confidence intervals for chinook life history groups. Data from Tables IV and V of Parker and Larkin (1959).

Life history group	No. of fish	Average size at ultimate annulus	Mean a	Confidence interval[a] $\bar{a} \pm t_{.05} s_{\bar{a}}$	
				Lower	Upper
0/2	27	20.8	34.10	32.06	36.14
0/3	150	27.7	29.82	28.98	30.66
0/4	60	33.3	27.49	26.11	28.87
0/5	8	37.6	25.89	20.34	31.44

[a]While the variance of a was calculated using the number of observations (i.e. number of fish times number of observations per fish, less one), standard error was calculated using above variance and number of fish.

TABLE II. Average annual size-specific instantaneous growth rates and 0.95 confidence intervals for each life history type. "Lower" and "upper" refer to confidence intervals.

	Life history type											
	0/2			0/3			0/4			0/5		
l_t	Lower	Mean	Upper	Lower	Mean	Upper	Lower	Mean	Upper	Lower	Mean	Upper
5	3.88	4.00	4.11	3.68	3.74	3.79	3.49	3.59	3.68	3.04	3.47	3.84
10	2.32	2.41	2.50	2.17	2.21	2.26	2.03	2.10	2.17	1.70	2.02	2.29
15	1.61	1.69	1.76	1.50	1.53	1.56	1.38	1.44	1.49	1.14	1.37	1.59
20	1.21	1.28	1.34	1.12	1.15	1.17	1.03	1.07	1.12	0.84	1.03	1.20
25	0.96	1.01	1.06	0.89	0.91	0.93	0.81	0.85	0.88	0.65	0.81	0.95
30	0.79	0.83	0.87	0.72	0.74	0.76	0.66	0.69	0.72	0.53	0.65	0.78
35	0.66	0.70	0.74	0.61	0.62	0.64	0.55	0.58	0.61	0.44	0.55	0.65
40	0.57	0.60	0.63	0.52	0.53	0.55	0.47	0.50	0.52	0.38	0.47	0.56

presents computed size specific values of g, and the 0.95 confidence intervals. Figure 1 presents the instantaneous relative growth rate curve as a function of size for each life history type.

CRITICAL SIZE

Critical size has been defined as the size at which the instantaneous relative rates of growth and natural mortality are equal. Also included in Fig. 1 is the zone of instantaneous natural mortality rate. The fact that the size-specific instantanous relative growth rate (weight) for each life history type lies above the zone of instantaneous natural mortality clearly demonstrates that, on the average, critical size is never attained. The total mass of each life history group gains weight until the ultimate year, the only exception being the very largest members of the slow growing 0/5 group[7]. The 0/2, 0/3 and 0/4 groups mature and leave the marine environment before the instantaneous growth rate decreases to equality with the instantaneous natural mortality rate. If maximum yield, in pounds of fish from the stock, is desired, fishing should be restricted to the maturing individuals in their ultimate year.

SIZE LIMITS

If fishing is allowed on the immature stock a dilemma arises in choosing a size limit. It is impractical, if not impossible, to separate the life history groups while immature. Yet a size limit which would allow cropping, say the 0/2 group, would be wasteful of the potential growth obtainable from the older life history types. At present, management agencies of the Pacific coast of North America enforce size limit restrictions which in effect prevent the landing of fish less than 25.0 inches fork length. Figure 1 shows that fish maturing at earlier ages than 2+, and some portion of the 0/3 group, are excluded entirely from the catch. This loss might be offset by gain in weight of older life history types, depending upon their relative strength within the year class, *provided* that release mortality is negligible.

Mortality associated with catching by troll and releasing feeding chinook salmon has been studied by Parker and Black (1959) and Parker, Black and Larkin (1959). These authors have shown that significant mortality ensues after such treatment and is ascribable to hyperactivity. Additional mortality from direct injury has been recorded (Parker and Kirkness, 1956, and subsequent unpublished observations) amounting to approximately 20%. Milne and Ball (1956) reported total mortality of troll caught coho salmon (*O. kisutch*) when hooked in the gills, and 50% mortality of fish hooked in the eye. Milne and Ball further report 12 of 67, or 18%, of the fish caught were either drowned or so severely hooked that they were nearly dead and unfit for tagging.

[7]Life history type is denoted by the number of annuli completed in fresh water and in salt water, thus 0/2 denotes a type having gone to sea during the first year of life and forming two annuli in salt water. The total age is 0 + 2 = 2 and spawning occurred in the third year of life.

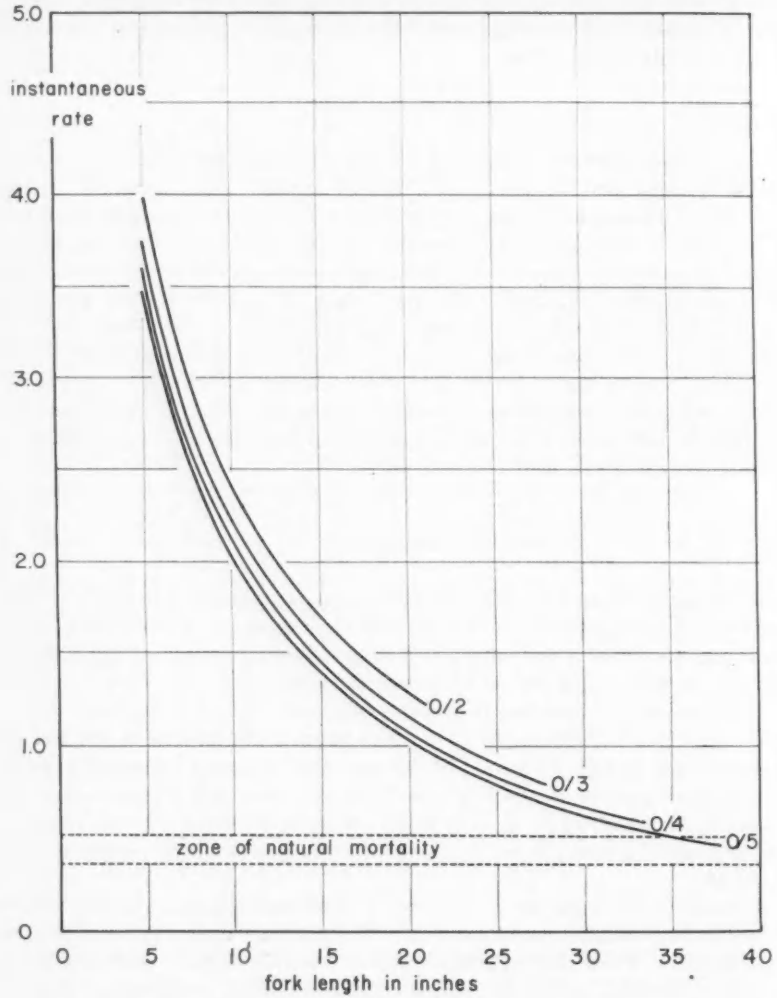

FIG. 1. Length-specific annual instantaneous growth (weight) rates of life history groups of chinook salmon compared with zone of instantaneous natural mortality rate.

These observations may be combined with delayed fatigue mortality observations into a single instantaneous rate. The instantaneous rate from physical injury is estimated by $-\ln(1-0.2) = 0.223$. The delayed mortality rate from fatigue incurred by hooking and releasing lies between the 0.95 confidence limits (Parker and Black, 1959):

$$-\ln(1-0.40) = 0.512, \text{ and } -\ln(1-0.86) = 1.966;$$

while the empirically observed estimate is $-\ln(1-0.71) = 1.236$. The total instantaneous rate of mortality ascribable to catching and releasing lies within the limits 0.735 and 2.189. When instantaneous natural mortality is added (0.36 to 0.51) the most optimistic expectation of mortality for the first year after release is an instantaneous rate in excess of 1.0, and the rate may be as high as 2.5. This zone of total instantaneous mortality (exclusive of fishing) in relation to size-specific relative growth rate is graphically presented in Fig. 2. Ignoring any production lost from the 0/2 group of fish, a size limit of *not more* than 22.5 inches and probably much less (approximately 15.0 inches for a mean value) could be justified as a restriction to increase the yield in pounds from the stock.

Other advantages may possibly accrue from a size restriction, such as increased spawning escapement, production of a larger size (hence more valuable product)[8] and the avoidance of undersized stocks by the fishermen. 1. The relationship between escapement and return is not known at present for chinook and therefore possible advantages from increased spawning cannot be evaluated. It is certain, however, that the size limit (25.0 inches) applied to mature segments of the stock results in increased escapement of the *male* fraction only (Anon., 1951). 2. The increase in value with increased size has not been analyzed, but is listed as a possible benefit. 3. Avoidance of accumulations of undersized fish by the fishermen has not been generally investigated. The degree to which a size limit will influence such avoidance will depend upon the numbers of "legal" fish contained in the accumulation. This fraction will be dynamic and hardly susceptible to a generalized statement.

There remains the possibility that natural mortality rate may increase as the mature segment of the stock becomes increasingly concentrated along migration routes, in channels, and in estuaries. Again no data appear to be published on this question, hence no evaluation of this effect on critical size can be made. If an increase in natural mortality rate accompanies maturity while individuals are still in the marine environment, a critical size might be reached at an immature stage, thus indicating the need of a fishery on the immature stock. These remain as problems for future research.

[8]1958 price structure was such that chinook over 10 pounds (approximately 28 inches) brought 1½ times the price per pound paid for fish under that size.

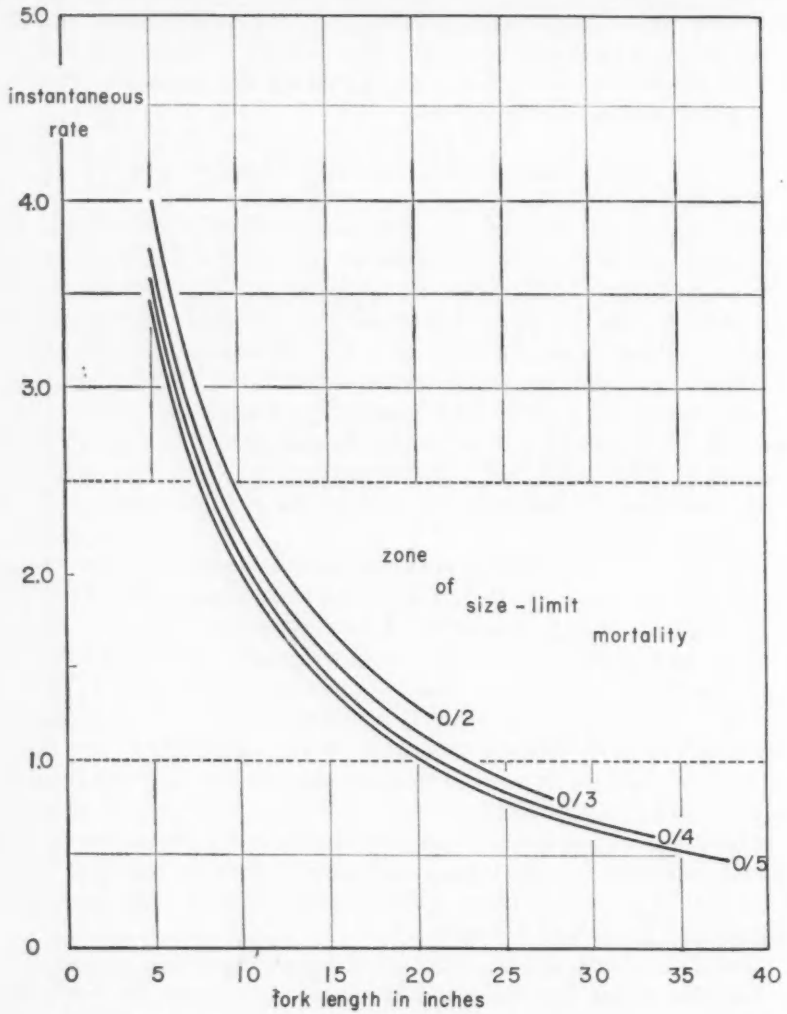

FIG. 2. Length-specific annual instantaneous growth (weight) rates of life history groups of chinook salmon compared with zone of "size limit mortality".

CONCLUSIONS

With the information now available the following general conclusions may be put forward as means of increasing the yield in pounds from the stock of chinook, anticipating no net increase in fishing intensity.

(1) Fishing should be restricted to the maturing stock. This may be accomplished by restricting the area and time of fishing.

(2) Under conditions of (1) above size limits should be abolished and the use of non-selective gear encouraged.

(3) If fishing is to be permitted on the immature stocks, an increase in yield cannot be expected from a size limit restriction. A type of troll gear might be found which is selective for larger fish; however, this would sacrifice the yield possible from the shorter life-history types.

ACKNOWLEDGMENTS

The author gratefully acknowledges the constructive criticism given by Drs P. A. Larkin, C. C. Lindsey and W. A. Clemens of the Department of Zoology, University of British Columbia, and Dr W. E. Ricker of the Fisheries Research Board of Canada. This study was made while the author was on educational leave from the Alaska Department of Fish and Game. This organization is gratefully acknowledged for funds and data supporting the study.

REFERENCES

ALLEN, K. RADWAY. 1953. A method for computing the optimum size-limit for a fishery. *Nature*, No. 4370, p. 210.

1954. Factors affecting the efficiency of restrictive regulations. I. Size limits. *New Zealand J. Sci. and Tech.*, Sect. B, **35**(6): 498–529.

ANON. 1951. Annual report of the Alaska Department of Fisheries. No. 3. Biological Investigations, pp. 20–42.

BEVERTON, R. J. H., AND S. J. HOLT. 1957. On the dynamics of exploited fish populations. *U.K. Min. Agr. Fish.* and *Food, Fisheries Investigations*, Ser. II, **29**: 1–533. etc.

CALHOUN, A. J., D. H. FRY, JR, AND E. P. HUGHES. 1951. Plastic deterioration and metal corrosion in Petersen disk fish tags. *California Fish* and *Game*, 37(3): 301–314.

FRY, D. H., Jr, AND ELDON P. HUGHES. 1951. The California salmon troll fishery. *Bull. Pac. Mar. Fish. Comm.* No. 2: 7–42.

KAUFFMAN, D. R. 1951. Research report on the Washington State offshore troll fishery. *Bull. Pac. Mar. Fish. Comm.* No. 2: 77–91.

LARKIN, P. A., J. G. TERPENNING AND R. R. PARKER. 1957. Size as a determinant of growth rates in rainbow trout *Salmo gairdneri*. *Trans. Am. Fish. Soc.* for 1956, **86**: 84–96.

MILNE, D. J. 1957. Recent British Columbia spring and coho salmon tagging experiments, and a comparison with those conducted from 1925 to 1930. *Bull. Fish. Res. Bd. Canada*, No. 113, 56 pp.

MILNE, D. J., AND E. A. R. BALL. 1956. The mortality of small salmon when caught by trolling and tagged or released untagged. *Fish. Res. Bd. Canada, Pacific Progress Report*, No. 106, pp. 10–13.

1958. The tagging of spring and coho salmon in the Strait of Georgia in 1956. *Ibid.*, No. 111, pp. 14–18.

NEAVE, FERRIS. 1951. Observations on troll-caught salmon of the west coast of Vancouver Island, 1949. *Bull. Pac. Mar. Fish. Comm.*, No. 2, pp. 94–101.

PARKER, R. R., AND E. C. BLACK. 1959. Muscular fatigue and mortality in troll-caught chinook salmon (*Oncorhynchus tshawytscha*). *J. Fish. Res. Bd. Canada*, **16**(1): 95–106.

PARKER, R. R., E. C. BLACK AND P. A. LARKIN. 1959. Fatigue and mortality in troll-caught Pacific salmon (*Oncorhynchus*). *Ibid.*, **16**(4): 429–448.

PARKER, R. R., AND WALTER KIRKNESS. 1956. King salmon and the ocean troll fishery of southeastern Alaska. *Alaska Dept. Fish., Res. Rept.*, No. 1, 64 pp.

PARKER, R. R., AND P. A. LARKIN. 1959. A concept of growth in fishes. *J. Fish. Res. Bd. Canada*, **16**(5): 721–745.

RICKER, W. E. 1945. A method of estimating minimum size limits for obtaining maximum yield. *Copeia* for 1945, No. 2, pp. 84–94.

1958. Handbook of computations for biological statistics of fish populations. *Bull. Fish. Res. Bd. Canada*, No. 119, 300 pp.

Observations on Sound Scatterers in Newfoundland Waters[1]

By Steinar Olsen

Fisheries Research Board of Canada
Biological Station, St. John's, Nfld.

ABSTRACT

A sound scattering layer in the warm surface water or at the depth of the summer thermocline has frequently been observed off the southern and western coasts of Newfoundland. The scatterers have not been identified, but are most likely of biological nature.

An observation of a diurnal vertical migration of a deeper scattering layer is reported.

INTRODUCTION

While a good deal of literature has been published on sound scatterers in various parts of the world, notably in European waters, very little if anything has been reported on observations of such phenomena in Canadian Atlantic waters.

The present observations were made on board the M.V. *Matthew II* during 1957 and 1958, incidentally to the main work of herring research and exploratory fishing on the south and west coasts of Newfoundland.

The vessel was equipped with a Simrad Type 510-3 echo sounder (38.5 kc/s) with an additional transducer for horizontal ranging. This apparatus was used extensively over large areas for the purpose of fish location, and many echograms have been produced.

Many of the echograms show recordings of sound scatterers distributed randomly or in well defined layers; and although hardly any effort was spent in investigating the cause of such recordings, the observations are themselves of interest.

THE OBSERVATIONS

A brief account of where and when the vessel has been operating since the echo sounder was installed in July 1957 is given in Table I. The occurrence of well defined scattering layers is recorded in the right hand column.

Recordings of randomly distributed scatterers were made on all cruises. Such recordings were very common in the summer months, less frequent in fall and rare in the winter.

The vessel was usually drifting at night, hence only on relatively few occasions was echo sounding carried out after darkness. The limited amount of night-

[1]Received for publication November 10, 1959.

J. Fish. Res. Bd. Canada, 17(2), 1960.
Printed in Canada.

time observations does not reveal any difference between day and night in the vertical or horizontal distribution of sound scatterers.

The recordings of the scattering layers are characterized by vertical thinness, frequently of about one pulse length only, and by horizontal extensiveness. On

TABLE I. Records of operations of the M.V. *Matthew II* from July 1957 to September 1958, and observations of sound scattering layers.

Area	Date	Observations of scattering layers
	1957	
West coast from Strait of Belle Isle to St. George's Bay	July 30–Aug. 14	Numerous
South coast from Fortune Bay to Port aux Basques	Aug. 20–Sept. 30	Occasionally offshore in August
West coast, St. George's Bay –off Portland Creek	Oct. 12–Nov. 16	Very rare
Fortune Bay	Nov. 18–Dec. 7	None
	1958	
Placentia Bay and Fortune Bay	Jan. 14–Apr. 3	None
St. Mary's Bay, Hermitage Bay and St. George's Bay	May 26–June 19	Very rare
West coast from Strait of Belle Isle to Cape St. George	July 2–Sept. 12	Numerous

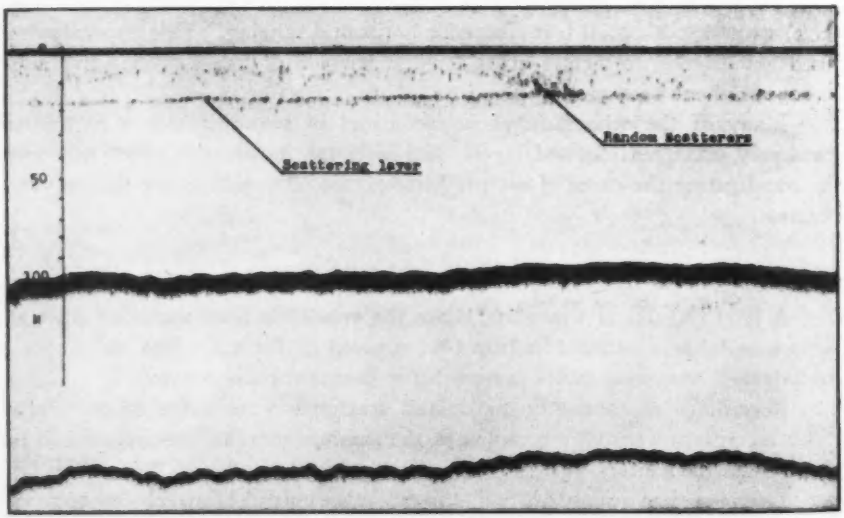

FIG. 1. Recordings of a scattering layer with random scatterers above. August 1, 1957, off Bay of Islands.

rare occasions double layers about 2 or 3 m apart were recorded, but never over any large distance. A typical echogram with recordings of a layer and some random scatterers above this is shown in Fig. 1.

The data from those occasions when a scattering layer was present, and when simultaneous observations of the temperature distribution were available have been summarized in Table II.

The depth range of the layer was measured from the echograms. While the depth of the top of the layer is thus fairly accurate, the vertical extent of the layer will appear a little larger than it was in reality.

Data on the temperature distribution in the water were obtained from Bathythermograph casts. The depth at the "top of the thermocline" is here defined as the depth where the abrupt change in temperature occurs, and it is usually fairly accurately located on a Bathythermograph chart.

FIG. 2. Chart showing place names mentioned in Table II.

TABLE II. Depth range of scattering layer and simultaneous observations on temperature distribution.

Stn. No.	Date	Locality	Top of layer		Bottom of layer		Other scatterers	Top of thermocline	
			Depth	Temp.	Depth	Temp.		Depth	Temp.
			m	°C	m	°C		m	°C
	1957								
169	July 30	Off C. St. George	15	13.4	16	13.4	None	18	13.4
170	30	Off C. St. George	15	13.4	20	13.3	None	21	13.3
171	30	Off Bay of Islands	19	11.7	20	10.5	Above	16	13.5
172	30	Off Bay of Islands	17	13.6	18	13.6	Above	19	13.6
173	30	Off Bay of Islands	5	14.5	12	13.0	None	12	13.0
174	30	Off Bonne Bay	14	12.6	18	8.9	Above	12	12.8
175	31	Off Bonne Bay	19	12.2	20	11.1	Above	18	13.2
179	31	Off Cow Head	15	11.6	17	10.0	Above	14	10.2
180	Aug. 2	St. George's Bay	28	8.3	35	4.0	Above	22	11.0
184	5	St. George's Bay	12	13.9	13	13.4	None	13	13.4
190	7	Off Table Pt.	6	15.0	9	14.5	None	6	15.0
193	8	Off Flowers Cove	8	11.7	10	11.4	None	11	11.1
195	8	Off Flowers Cove	8	12.8	10	12.7	Above	10	12.7
205	12	Off Riche Point	11	14.9	13	14.7	Above	13	14.7
206	12	Off Riche Point	7	15.0	9	14.9	None	18	14.6
208	13	St. George's Bay	21	14.0	23	13.4	None	18	15.6
211	21	Fortune Bay	9	17.1	10	17.0	None	19	16.6
229	24	Burgeo Bank	9	16.3	11	16.1	None	11	16.1
230	24	Burgeo Bank	10	15.0	11	13.9	None	9	16.0
233	26	Off La Poile Bay	12	17.0	13	16.9	None	14	16.8
234	26	Off La Poile Bay	18	15.6	19	14.7	None	13	17.1
235	26	Off La Poile Bay	10	14.5	11	14.3	None	6	16.1
	1958								
88	July 4	Off Bay of Islands	8	9.5	12	9.4	Above	18	9.0
90	4	Off Bay of Islands	9	9.6	12	9.4	None	14	9.3
91	4	Off Bay of Islands	11	9.4	13	8.9	None	9	10.0
101	5	Off Bonne Bay	14	8.6	17	8.4	Above	8	10.6
110	17	Off Riche Point	6	13.3	12	9.5	None	6	13.3
139	Sept. 6	Off Ferolle Point	6	12.8	9	12.8	Above	31	13.0
142	6	Off Anchor Point	8	12.8	12	10.3	Above	No defined thermocline	
153	10	Off Bonne Bay	20	11.9	22	7.8	None	17	12.2
154	10	Off Bonne Bay	25	10.0	30	5.3	None	24	12.4

DISCUSSION

The general hydrographic condition in Newfoundland waters is in the summertime characterized by a shallow layer of relatively warm water on top, covering a fairly extensive layer of very cold water. Where the depth is great enough, water of medium temperature is found below this cold intermediate water of Arctic origin (see, for instance: Lauzier, Trites and Hachey, 1957; Lauzier and Bailey, 1957).

It appears from Table II that the scattering layer was sometimes situated entirely within the warm layer of surface water, and at other times in the transition layer between the surface layer and the very cold water below. We may therefore disregard the possibility of the echoes being directly related to the large vertical gradient in density at the depth of the thermocline, and assume the cause of the echoes to be of biological nature.

Apart from some plankton hauls made in September 1957 in Fortune Bay, showing an abundance of ctenophores where numerous scatterers were randomly distributed in the surface waters, no attempt was made to identify the cause of the echo recordings.

Table II also shows that the scattering layer was generally situated in relatively warm waters of 8.5° to 17.0°C, occasionally extending to depths with temperatures as low as 4.0°C. Random scatterers were frequently recorded above the layer, but never below.

It would thus appear that the cold intermediate layer of water formed an effective barrier for a wide vertical distribution of the sound scatterers, and confined them to the warm surface waters and the transition layer between these and the much colder waters below.

Various authors (Cushing, Lee and Richardson, 1956; Weston, 1958) have reported observations of sound scattering layers associated with the presence of small fish or plankton organisms at the depth of the summer thermocline in the North Sea. Weston found random scatterers below the thermocline in day-time, but not at night. Because of the extreme coldness of the water below the thermocline a similar diurnal migration would very unlikely occur in Newfoundland waters, and as mentioned previously, the limited material of night observations shows no scatterers in the cold waters below the thermocline.

The shallow scattering layer observed in the North Sea is found to be very closely related to the depth of the thermocline, and Weston suggests that the echo recordings would provide a means of continuous measurements of thermocline depth.

As shown here the depth of the scattering layer does not always correspond to that of the thermocline. The deviations were sometimes fairly large, particularly in 1958 when the temperature gradients in the transition layer were relatively small. However, under the more "normal" conditions in 1957 there seemed to be some relation between the position of the scattering layer and the depth of the thermocline.

On the chart in Fig. 3 is plotted the distribution of sound scatterers in the top layer of water recorded from July 3 to 20, 1958. It appears that there are several discontinuous areas with sound scatterers of a density level above the minimum required for detection by the echo sounder. No direct relationship has been found between the horizontal temperature distribution and the extent

of sound scatterers. A similar distribution of sound scatterers was found in this area in the early part of August 1957, but the observations are not directly comparable with those in 1958 because the echo sounder was not used consistently at the same amplification setting in 1957.

Thus, if these sound scatterers are mainly plankton organisms, and some relation can be established between plankton abundance and quantitative indices of echo recordings, for instance as estimated by Cushing (1952), an echo survey would provide a most useful aid in establishing a picture of the plankton distribution of an area.

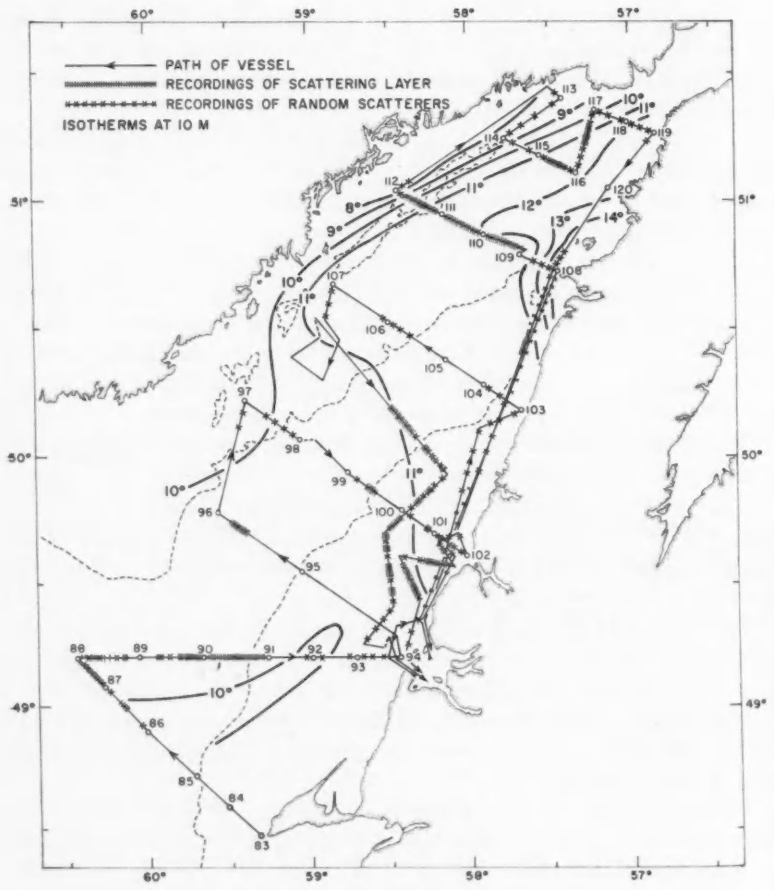

FIG. 3. Distribution of sound scatterers in the surface layer of water from July 3 to 20, 1958, off the west coast of Newfoundland.

AN OBSERVATION ON DIURNAL VERTICAL MIGRATION OF A DEEP SCATTERING LAYER

During the night of July 4 to 5, 1958 an interesting sequence of echo recordings was made. The vessel was drifting with a fleet of herring nets in the Gulf of St. Lawrence, starting in a position of 50°03′15″N, 59°05′15″W. The drift during the night was about 2½ nautical miles in an easterly direction. The wind was westerly, force 2 Beaufort, and the sky was partly overcast.

At 2010 hours (Nfld. Standard Time), just about dusk, a layer of 2 to 3 m thickness was recorded at a depth of 151 to 154 m. This layer was recorded more or less continuously for the next two hours, and during the first 50 minutes it ascended 120 m. Between 2200 and 2300 hours the layer dissolved into numerous individual scatterers which remained in the upper 40 to 50 m until 0500 hours in the morning. From 0500 to 0700 hours again a clearly defined layer (sometimes two) was observed descending rapidly to a depth of 160 m.

The types of the recordings made at various hours are shown in Fig. 4, and Fig. 5 shows graphically the general position of the echo giving bodies during the 11-hour period.

The vertical temperature distribution as recorded with a Bathythermograph is given in Fig. 6. It is noticed that the most rapid vertical movements took place in water of low temperatures, less than 2°C.

The result of the night's drift net fishing was one herring only. Numerous trials at midnight with a cod jigger lowered to the depth of the scatterers yielded nothing. No other way of identifying the cause of the echoes was tried.

The rapid ascent of the scattering layer at a rate of nearly 2.5 m per minute over an extensive period of time would indicate highly mobile organisms of a fairly large size. However, a vertical movement from 150 to 30 m is equivalent to a

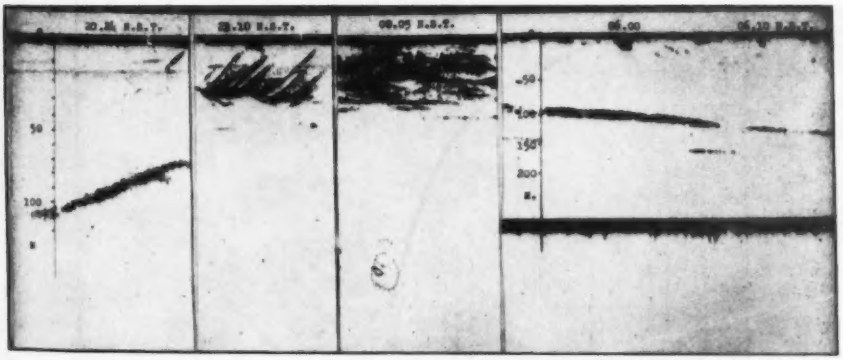

FIG. 4. Recordings of a scattering layer ascending from deeper waters in the evening, dissolving into numerous individual traces in the middle of the night, and descending by daylight in the morning.

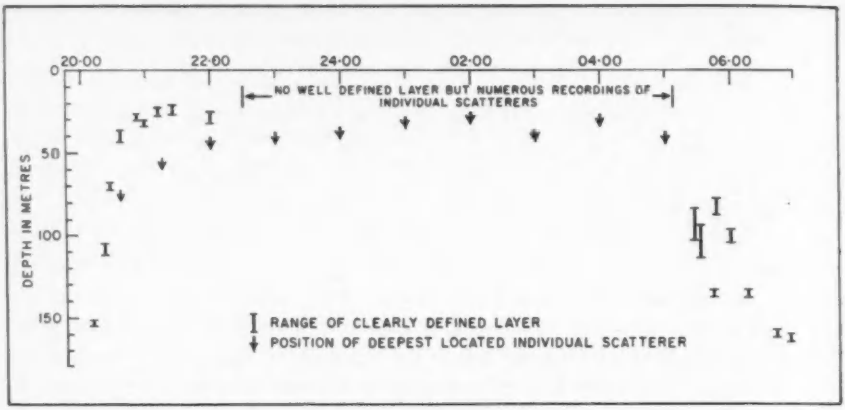

FIG. 5. Bathymetric distribution of scatterers from 2000 hours July 4 to 0700 hours July 5, 1958.

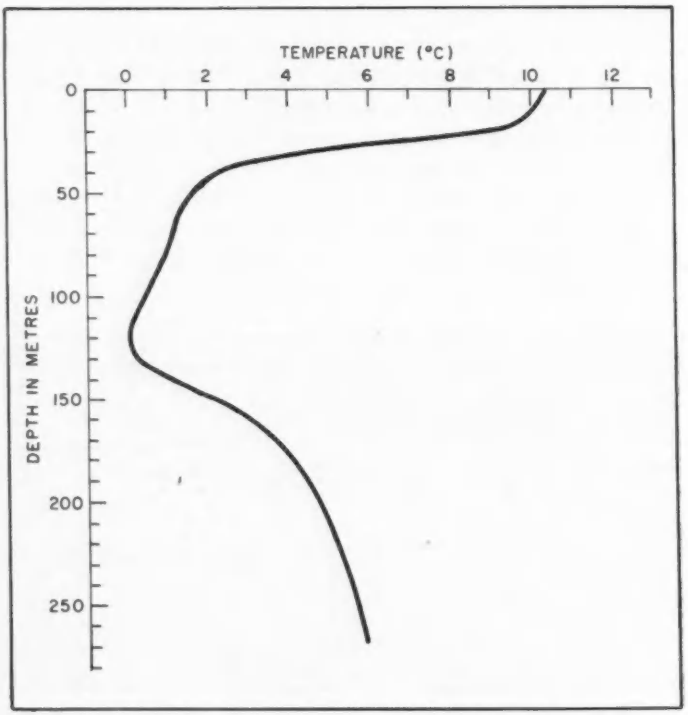

FIG. 6. Vertical temperature distribution at 1955 hours July 4, 1958, in position 50°03′15″N, 59°05′15″W.

four fold decrease in pressure and this decrease took place during a period of 50 minutes only. It is therefore very unlikely that the records could be caused by a physoclist fish.

The recordings made about 2110 hours show traces of numerous individuals ascending from the main layer at 25 to 30 m depth to about 5 to 7 m below the keel, at a rate of over 10 m per minute. A few similar recordings were made before the main layer had reached this depth range, and it would therefore seem that these recordings were caused by other organisms, possibly herring or other fast-swimming fishes.

REFERENCES

CUSHING, D. H. 1952. Echo-surveys of fish. *J. Cons. Int. Explor. Mer*, **18**: 45–60.

CUSHING, D. H., A. J. LEE AND I. D. RICHARDSON. 1956. Echo traces associated with thermoclines. *J. Mar. Res.*, **15** (1): 1–13.

LAUZIER, L., AND W. B. BAILEY. 1957. Features of the deeper waters of the Gulf of St. Lawrence. *Bull. Fish. Res. Bd. Canada*, No. 111, pp. 213–250.

LAUZIER, L., R. W. TRITES AND H. B. HACHEY. 1957. Some features of the surface layer of the Gulf of St. Lawrence. *Bull. Fish. Res. Bd. Canada*, No. 111, pp. 195–212.

WESTON, D. E. 1958. Observations on a scattering layer at the thermocline. *Deep-Sea Research*, **5**: 44–50.

Seasonal Distribution of Some Epipelagic Fishes in the Gulf of Alaska Region[1]

By Ferris Neave

Fisheries Research Board of Canada
Biological Station, Nanaimo, B.C.

and M. G. Hanavan

United States Fish and Wildlife Service
Seattle, Washington

ABSTRACT

Distribution of various species of fishes in the Gulf of Alaska region in early, middle and late summer of 1956 and 1957, as determined by fishing with surface gillnets, is plotted.

The surface area occupied by steelhead and by four species of Pacific salmon is considerably reduced during the progress of the season. There is a large northward shift of the northern limits of distribution of pomfret, blue shark, jack mackerel and albacore during the same period. There is no obvious seasonal change in the distribution of the salmon shark.

Seasonal changes in range of occurrence conform with temperature changes in the surface waters and are more extensive in the eastern part of the Gulf.

INTRODUCTION

In the fishing operations conducted on the high seas of the North Pacific since 1955 by research vessels implementing the program of the International North Pacific Fisheries Commission, emphasis has been placed on the problem of determining the areas of origin of the salmon found in various regions of the ocean. These operations, however, together with associated oceanographic surveys and observations, have also yielded information on general features of the distribution not only of salmon but of other species inhabiting the surface waters of the high seas.

In spite of the fact that fishing in these offshore waters has been limited to a period extending from May to September, pronounced seasonal changes in the distribution of various species have been found. Such changes are especially evident in the extensive range of latitude which has been covered by research vessels in and immediately south of the Gulf of Alaska.

[1]Received for publication September 25, 1959.

J. Fish. Res. Bd. Canada, 17(2), 1960.
Printed in Canada.

MATERIAL AND METHOD

The data which are used in this account were obtained in 1956 and 1957 by the following United States and Canadian vessels:

1956. United States: *Celtic, Mitkof, Paragon, Tordenskjold, John R. Cobb.*
Canada: *Key West II, Challenger.*

1957. United States: *Attu, Paragon, Pioneer.*
Canada: *Key West II, Fort Ross.*

In addition, certain records pertaining to the distribution of salmon and albacore made in the southern part of the region in 1956 by the United States vessel *John R. Manning*, operating from Hawaii, have been included.

The only gear used in compiling the record consisted of floating gillnets hanging from the surface to a depth of 20 feet. Four sizes of mesh were used, namely, $2\frac{1}{2}$, $3\frac{1}{4}$, $4\frac{1}{2}$ and $5\frac{1}{4}$ inches. The total length of nets set on each occasion varied from 300 to 2050 fathoms but was usually 900 fathoms or more.

Species whose size and habits make them vulnerable to such gear, and which are also sufficiently plentiful to provide seasonal comparisons, are not numerous in the offshore waters of the Gulf of Alaska. They include, however, the salmon shark (*Lamna ditropis* Hubbs and Follett); blue shark (*Prionace glauca L.*); coho salmon (*Oncorhynchus kisutch* Walb.); sockeye salmon (*O. nerka* Walb.); chum salmon (*O. keta* Walb.); pink salmon (*O. gorbuscha* Walb.); steelhead (*Salmo gairdneri* Richardson); pomfret (*Brama rayi* Bloch); jack mackerel (*Trachurus symmetricus* Ayres); albacore (*Thunnus alalunga* Bonnaterre).

The dates and positions of fishing stations, water temperatures and other information have been published in the Annual Reports of the International North Pacific Fisheries Commission for 1956 and 1957.

FINDINGS

Approximate fishing positions are shown in Fig. 1 to 7. They are grouped in three categories representing early, middle and late summer. The earliest records in the first group were about the middle of May. The latest dates for fishing were about September 20. The places at which catches of each species or group of species were made are represented by solid symbols. Symbols show presence or absence in the hauls. They do not make allowance for differences in quantity of gear or in number of fish caught. Some salient features of the diagrams are noted:

SALMON SHARK. This species was caught much more frequently in late summer than in the months of May, June and July. There is, however, no obvious pattern of seasonal change in distribution (Fig. 1). Although early season

records for the species in the northern part of the Gulf of Alaska are wanting, it is probably present there, since it has been taken in June at Latitude 55°N in the Bering Sea. It is possibly the only sizeable species of fish which can be expected to occur in the surface waters of all parts of the region under discussion at all seasons of the year.

PACIFIC SALMON. In Fig. 2 the four species of *Oncorhynchus* which were commonly taken in high seas fishing are treated as a single unit, since the differences in limits of distribution which may exist between them are too small to be apparent in a broad survey based on widely scattered observations. In May and June Pacific salmon were consistently present in catches made north of Latitude 45° or 46°N off the Washington coast. They were not present in lifts made a short distance farther south.[2] In July a restriction of distribution was apparent. By August there appeared to be a large region west of Vancouver Island and the Washington coast in which Pacific salmon were not available to offshore surface gillnets.

STEELHEAD. The seasonal pattern of catches (Fig. 3) is very similar to that of Pacific salmon.

POMFRET. All early summer catches of pomfret were made at or south of Latitude 50°N. With the progress of the season the species spread throughout the Gulf (Fig. 4).

BLUE SHARK AND JACK MACKEREL. These two unrelated species showed similar patterns of distribution (Fig. 5, 6). Early summer occurrences were restricted to the extreme south or southeast portion of the region investigated. During middle and late summer a large expansion of range took place. This expansion, however, was mainly confined to the eastern part of the Gulf.

ALBACORE. No albacore were taken in the region until after the middle of July. In August or September of both years the species was caught at Latitude 50°N in the eastern part of the region (Fig. 7).

TEMPERATURE

Surface temperatures encountered during these investigations ranged from 7.6°C to 17.2°C.[3] These limits are insufficient to cover the full range of tolerance of any of the species concerned. However they appear to embrace the highest

[2]While the ocean distribution of salmon at other seasons of the year is little known, in April, 1956, pink salmon were taken as far south as 41°28′N at Longitude 165°W by the United States vessel *Charles H. Gilbert* operating from Honolulu. It is possible that in the mid-Pacific the winter range extends even farther to the south, as surface temperatures below 13°C were reported on this meridian as far south as 38°N.

[3]Excluding a single set by the *Tordenskjold* on the edge of the region (Lat. 53°N. Long. 165°W, May 31, 1956) which showed a temperature of 4.1° and yielded sockeye and chum salmon.

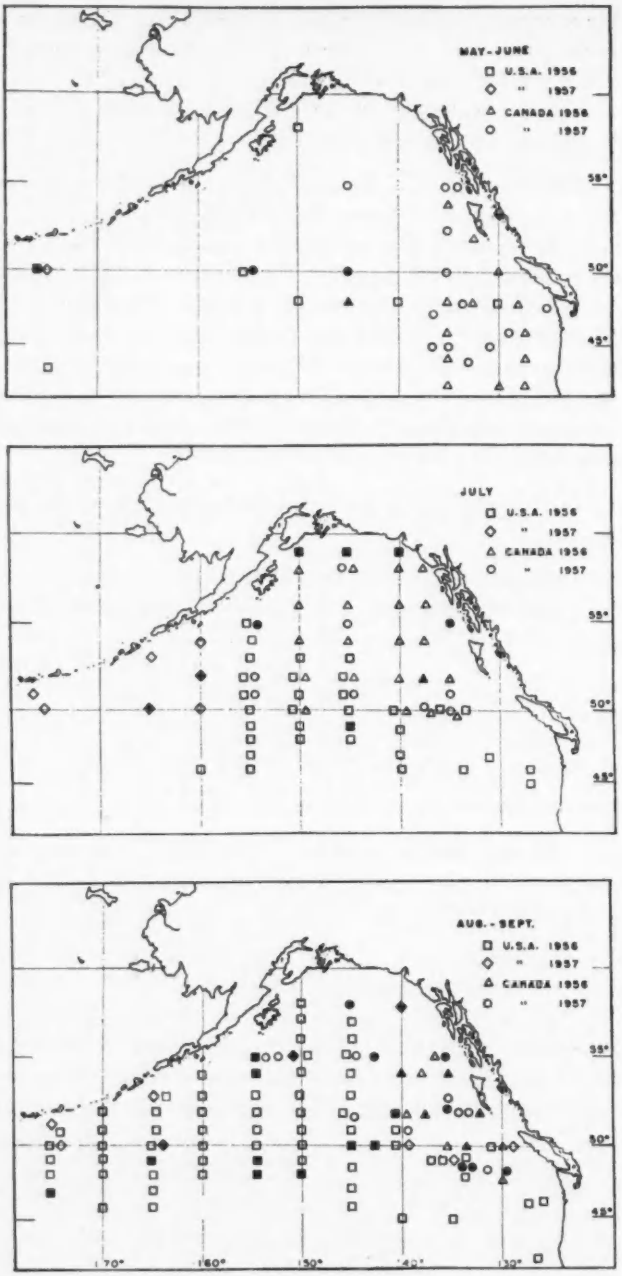

FIG. 1. Distribution of the salmon shark. (In Fig. 1 to 7, black symbols indicate occurrences, open symbols indicate fishing stations where the species in question was not taken.)

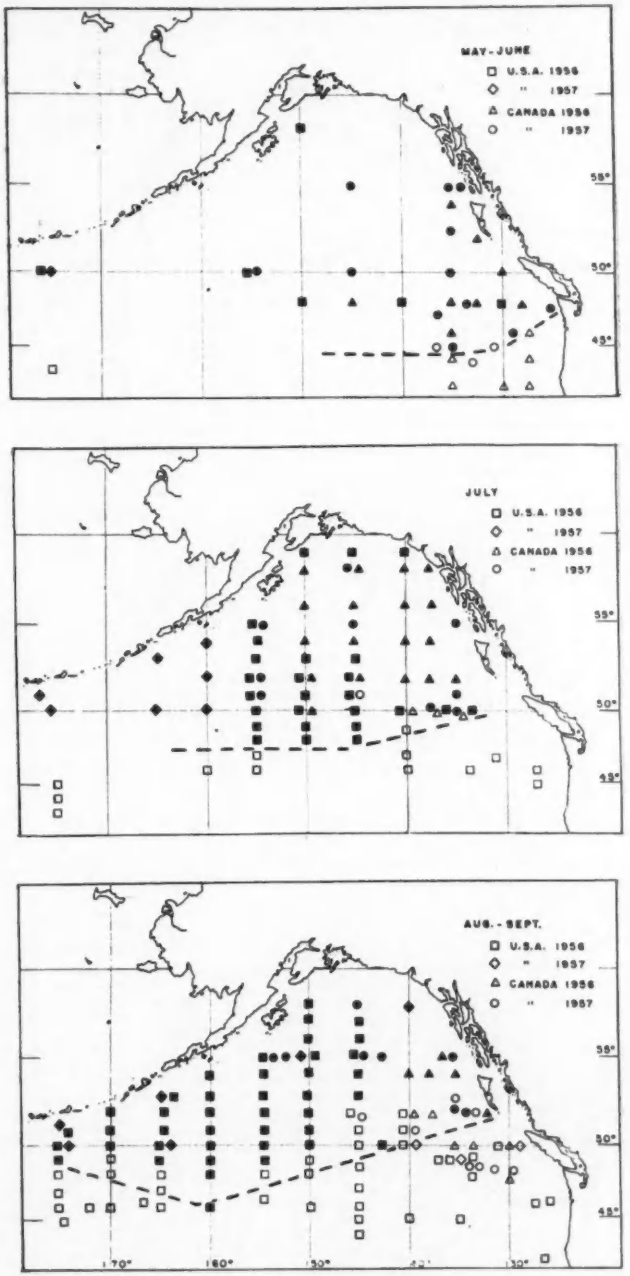

FIG. 2. Pacific salmon. The broken line represents the approximate southern limit of catch records.

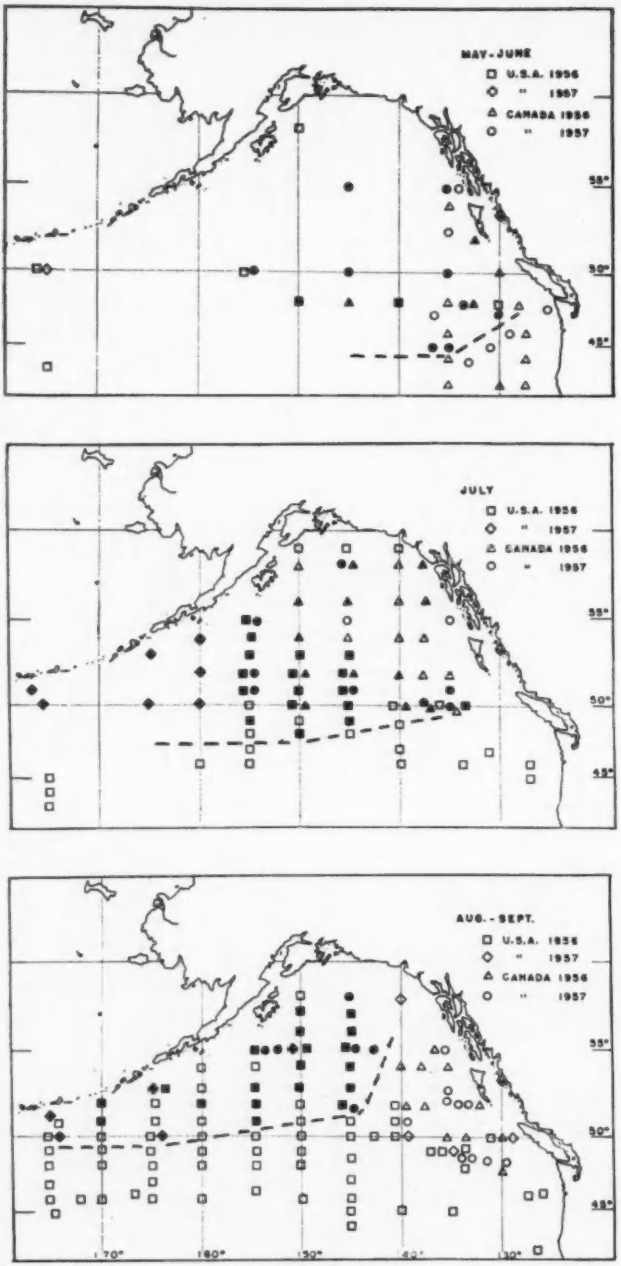

FIG. 3. Steelhead. The broken line represents the approximate southern limit of catch records.

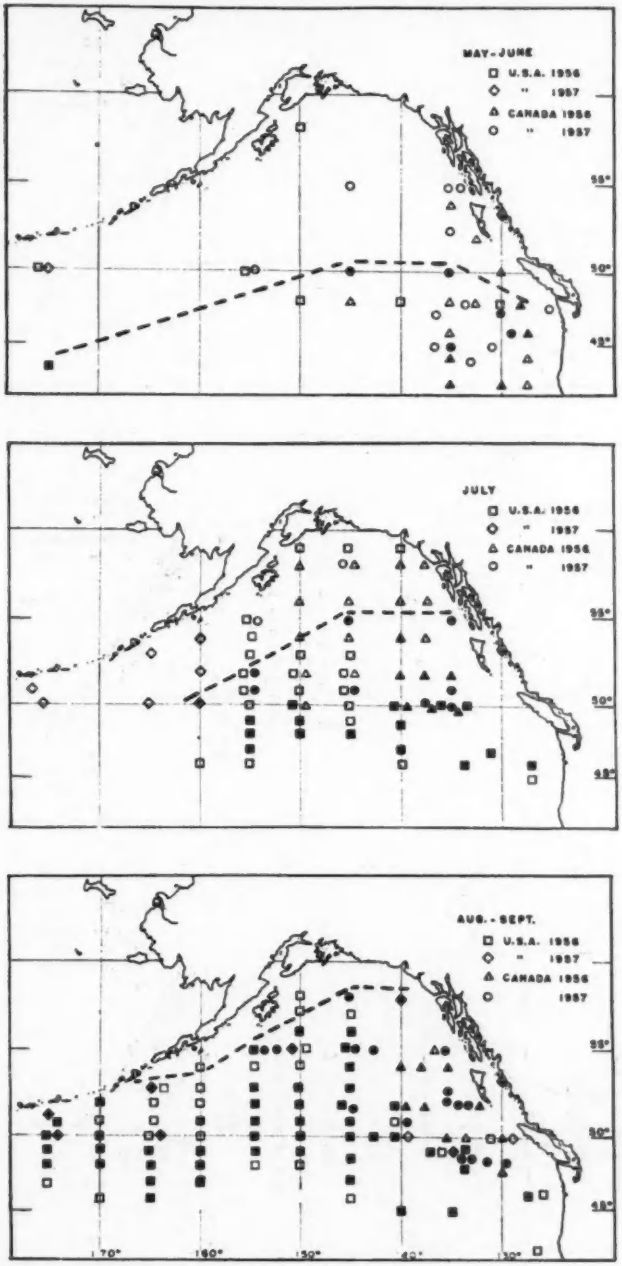

FIG. 4. Pomfret. The broken line represents the approximate northern limit of catch records.

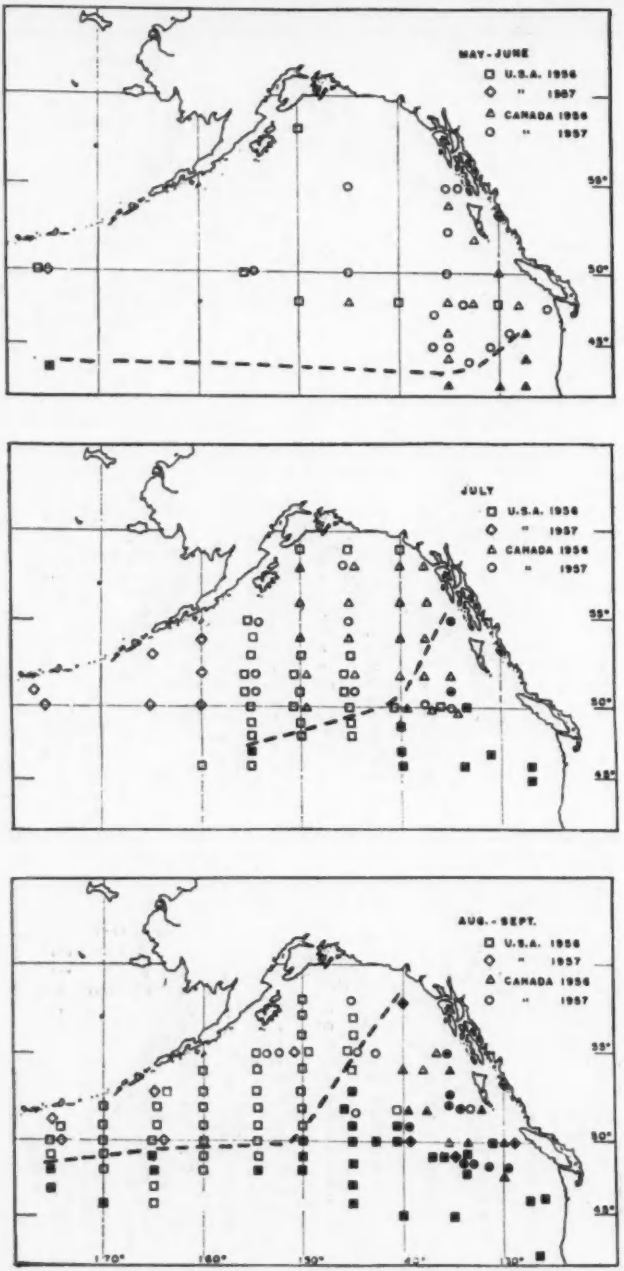

FIG. 5. Blue shark. The broken line represents the approximate northern limit of catch records.

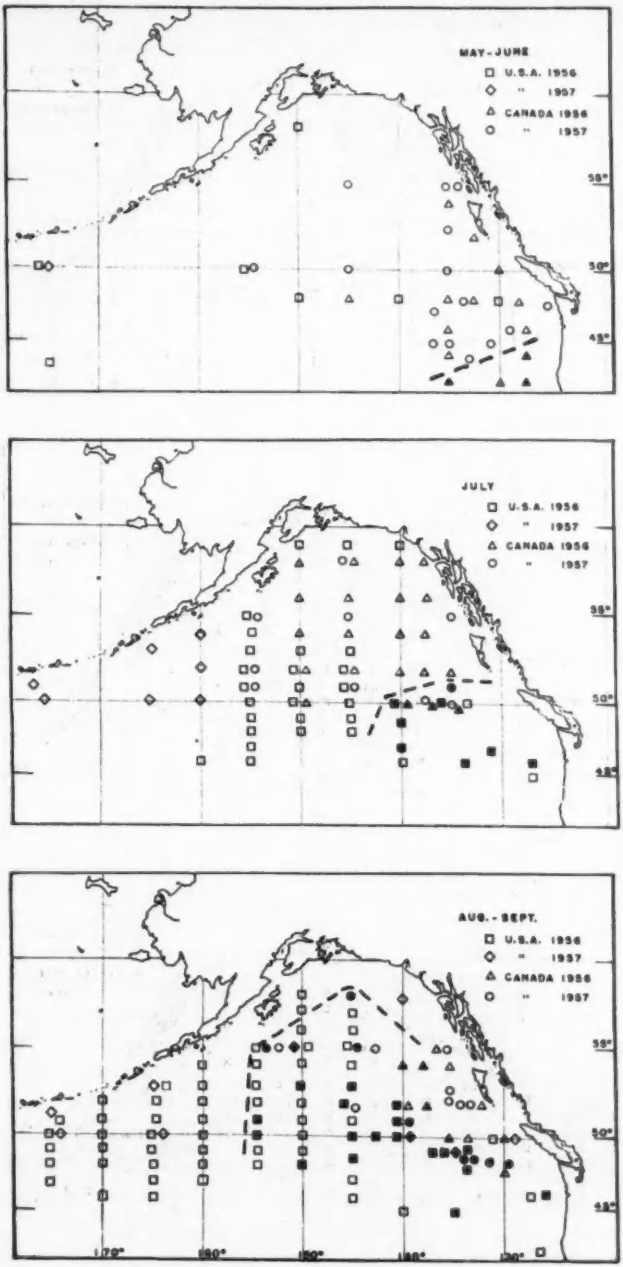

FIG. 6. Jack mackerel. The broken line represents the approximate northern limit of catch records.

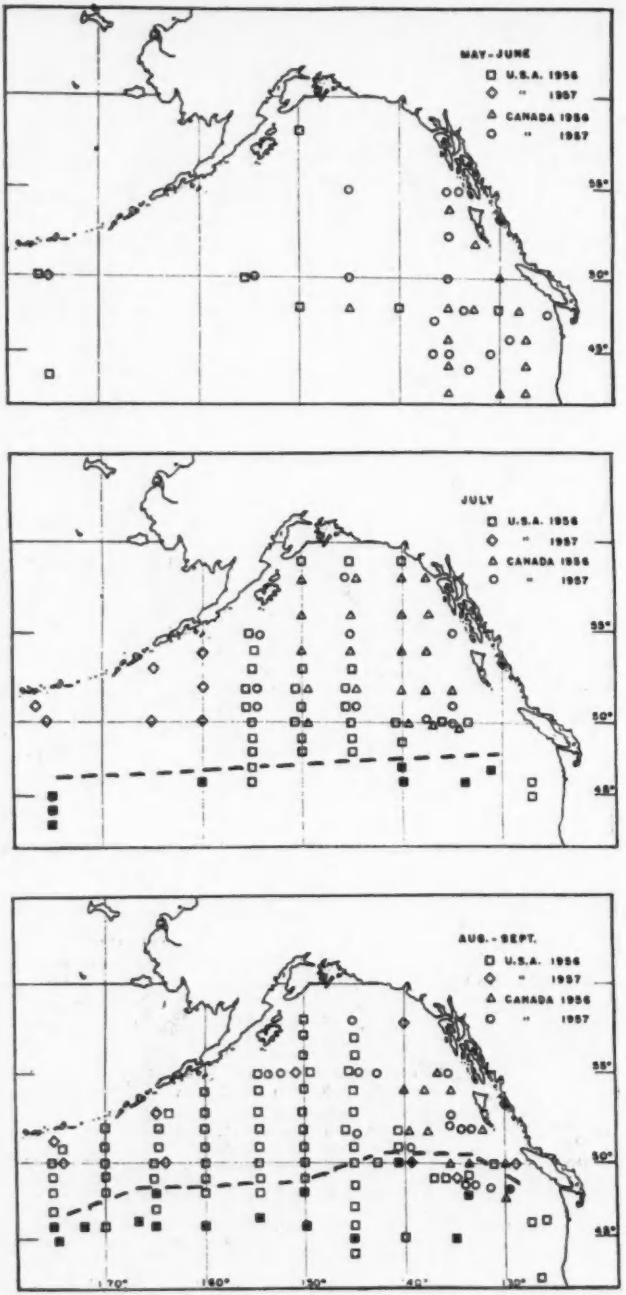

FIG. 7. Albacore. The broken line represents the approximate northern limit of catch records.

favourable temperatures for growing salmon and steelhead and the lowest temperatures in which pomfret, blue shark, jack mackerel and albacore commonly occur (Fig. 8).

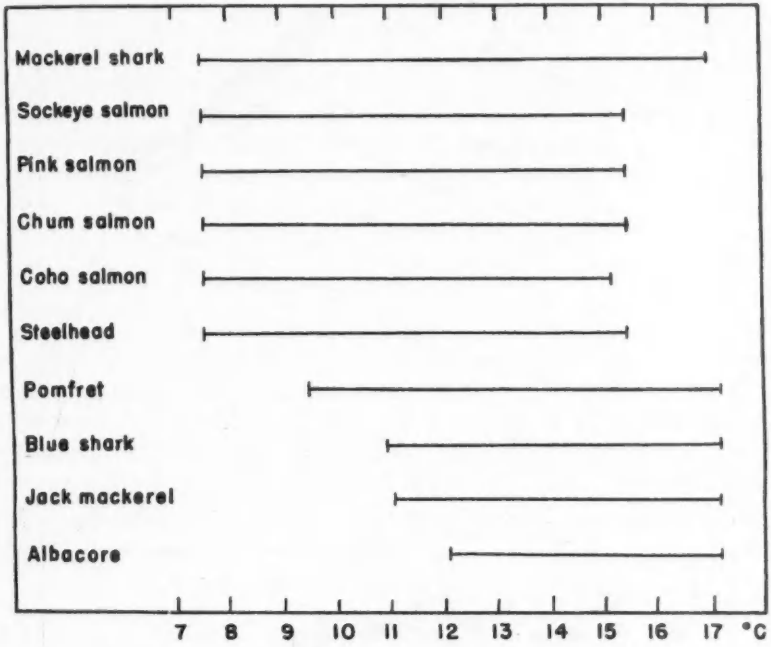

FIG. 8. Temperature range recorded for epipelagic fishes in the Gulf of Alaska region.

DISCUSSION

The locality records indicate the occurrence of broad directional movements for all the species discussed except the salmon shark. The distribution patterns conform with the general pattern of near-surface isotherms (Fig. 9). In accordance with the latter the northward withdrawal of cold-water species and the intrusion of warmer-water species during the summer are much more pronounced in the eastern part of the Gulf than farther west.

On the basis of two years' data the surface distribution of salmon in the region shrinks by some 300,000 square miles (777,000 km²) between early and late summer. A similar restriction of range is evident for the steelhead. Data are not yet available to show whether salmon and steelhead are present in this area at depths below the fishing range of surface gillnets.[4] However, if temperature

[4]On occasions when surface temperatures exceeded 15° (the approximate upper limit at which salmon were caught) water of this temperature was usually present within 25 metres of the surface.

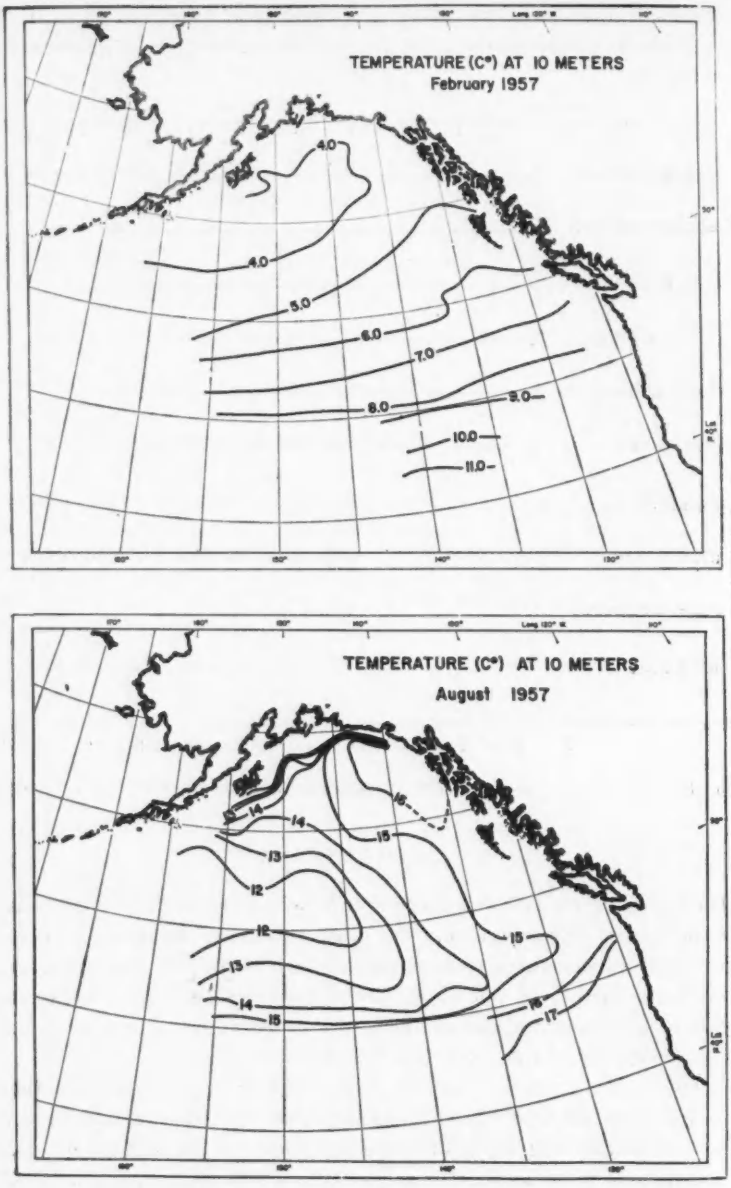

FIG. 9. Winter and late summer temperatures in the Gulf of Alaska region. (Figure supplied by the Pacific Oceanographic Group, Fisheries Research Board of Canada Biological Station, Nanaimo, B.C.)

is the main factor limiting distribution the surface records could certainly be expected to show horizontal changes of territory in the case of species coming from the south. These records suggest a seasonal expansion of range for jack mackerel, blue shark and pomfret amounting to from half to three-quarters of a million square miles (1,300,000 to 2,000,000 km^2) in the Gulf region. The boundaries drawn for these species in early and late summer indicate that the distances travelled in a northward direction by some fish during this period would be at least 500 sea miles (900 km) for pomfret, 700 miles (1300 km) for blue shark and 800 miles (1500 km) for jack mackerel. Inspection of dates and localities within a given year suggests that during the migration some pomfret average 8 or 9 miles (15–17 km) of northward movement per day and some jack mackerel 13 or 14 miles (24–26 km). Presumably the survivors of these summer invaders undertake a return migration later in the year, but of this nothing is known.

The annual variations which may occur in the territory occupied by the various species cannot be determined from two years' data. Surface water temperatures in the Gulf of Alaska were above average in the summer of 1957 and averaged 1° or 2° warmer than in 1956. A comparison between the findings of these two years suggests that this factor may have influenced the northern limits attained by blue shark and jack mackerel (Fig. 5, 6). However the main features and general scope of the seasonal changes in distribution seem to have been very similar.

The Food of the Redfish *Sebastes marinus* (L.) in the Newfoundland Area[1]

By D. G. Lambert[2]

Fisheries Research Board of Canada
Biological Station, St. John's, Nfld.

ABSTRACT

Samples of redfish stomachs were collected from the Newfoundland area and were analysed both qualitatively and quantitatively. In the sampled area the most important items of the diet of these fish are amphipods, fish and euphausians. There is a change in the diet of the redfish related to size. The redfish feeds on pelagic organisms and not on benthic forms.

INTRODUCTION

The redfish, *Sebastes marinus* (L.), is common in deep water throughout the Newfoundland area but it is only within recent years that it has become the object of a large commercial fishery. Thus many aspects of its feeding habits have not been intensively studied. Apart from the fact that only recently has this species assumed commercial importance in this area, the study of its feeding habits is hampered by the eversion of the stomachs of many of the fish as they are brought to the surface, with a consequent loss of the contents. Bigelow and Schroeder (1953) give some notes on the food of the redfish in the Gulf of Maine but they also state that most of the fish they have seen trawled had voided their stomach contents. Until now there has been no quantitative study of the food of the redfish in the Newfoundland area although Steele (1957) gives an account of the feeding of the redfish in the western Gulf of St. Lawrence. Boldovsky (1944) has shown that in the Barents Sea the food of the redfish is basically similar to that of the fish caught in Canadian waters.

At the time of collection no distinction was made between *Sebastes marinus mentella* Travin and *Sebastes marinus marinus* (L.) but it is likely that most of the fish were of the *mentella* type.

MATERIAL AND METHODS

The stomachs for analysis were collected in two ways. The majority were collected at sea either on one of the research vessels of the Biological Station or on commercial trawlers operating from St. John's, Nfld. These stomachs were tied off and preserved in formalin as soon as possible after the redfish were released

[1]Received for publication May 15, 1959.
[2]Present address: Zoological Society of London, Regent's Park, London, N.W.1, England.

J. Fish. Res. Bd. Canada, 17(2), 1960.
Printed in Canada.

on deck and the length, sex and maturity of the fish recorded. The remainder were collected from the samples of redfish brought into the laboratory as part of the normal redfish investigations, but these were generally in a poorer condition than those obtained at sea.

The individual stomachs in each sample were examined separately. Each stomach was opened and the contents emptied into a glass dish. The contents were then sorted into food groups and the volume of each group obtained by displacement. All organisms in each food group were identified to species where their state of preservation permitted.

The method used in presenting the data obtained from this investigation is based on that of McIntyre (1952). Three expressions are used to demonstrate the relative importance of the food groups in the diet. These are:

(i) The percentage occurrence of each group, i.e. the number of stomachs containing the group expressed as a percentage of the total number of stomachs *containing food*.

(ii) The volume of each food group expressed as a percentage of the total volume of all food in all stomachs.

(iii) The average volume of each food group in the stomachs where it occurrs.

Any of these expressions used alone, may be misleading but, considered together, they give a good estimate of the importance of the various food groups which make up the diet of the redfish.

From several parts of the Newfoundland area 2,669 stomachs have been examined and of these 627 (23%) contained food; of the others 1,361 (51%) were empty and 681 (26%) were everted and the contents lost. A number of stomachs which contained food could not be included in the quantitative analysis as they had been cut or damaged in other ways and some of the contents lost. They are included, however, in the qualitative data. The percentage of everted stomachs is smaller than was expected, but it is impossible to say whether or not those stomachs classed as empty were actually from fish which had not been feeding or whether the contents had been voided without the stomachs showing any indication of eversion.

ANALYSIS OF STOMACH CONTENTS

The stomach contents, on first analysis, were divided into a number of food groups as shown below.

Group (1)	Fish	Group (4)	Copepoda
Group (2)	Euphausiacea	Group (5)	Shrimp
Group (3)	Amphipoda	Group (6)	Other organisms.

The species, with an indication of their relative abundance, making up these food groups are shown in Table I.

The analysis of the stomachs, all samples combined, is summarized in Table II.

TABLE I. Species found in stomach contents of redfish. (+, Very rare; ++, rare; +++, common; ++++, abundant.)

	Species—arranged in food groups	Abundance
Group I	*Mallotus villosus* (Müller)	+
FISH	*Gadus callarias* Linné	+
	Sebastes marinus (Linné)	+
	Paralepis coregonoides borealis Reinhardt	+++
	Ceratoscopelus maderensis (Lowe)	+
	Myctophum punctatum Rafinesque	+++
	Benthosema glaciale (Reinhardt)	+++
	Notoscopelus elongatus (Costa)	++
	Bathylagus benedicti Goode & Bean	+
Group II	*Meganyctiphanes norvegica* (M. Sars)	++++
EUPHAUSIACEA	*Thysanoessa inermis* (Krøyer)	++++
	Thysanoessa raschii (M. Sars)	++++
Group III	*Themisto libellula* (Mandt)	++++
AMPHIPODA	*Themisto gaudichaudi* (Guérin)	++++
	Themisto abyssorum (Boeck)	+
	Pseudalibrotus glacialis G. O. Sars	+
	Pseudalibrotus nanseni G. O. Sars	+
Group IV	*Calanus finmarchicus* (Gunnerus)	++++
COPEPODA	*Calanus hyperboreus* Krøyer	++++
	Paraeuchaeta norvegica (Boeck)	++
	Paraeuchaeta glacialis (Hansen)	+
Group V		
SHRIMPS	*Pandalus borealis* Krøyer	++
Group VI	*Gonatus fabricii* (Lichtenstein)	++
OTHER ORGANISMS	*Clione limacina* (Phipps)	+
	Sagitta maxima (Conant)	+++

TABLE II. Analysis of redfish stomach contents—all samples combined. (Total stomachs included in analysis—563, total volume of food—3148.6 cc. Only undamaged stomachs containing food were used for Tables II–IV.)

Food groups	Occurrences	Percentage occurrence	Volume of food	Percentage of total volume of food	Average volume
	no.	%	*cc*	%	*cc*
Fish	67	11.9	800.8	25.4	12.0
Euphausiacea	221	39.3	541.5	17.2	2.5
Amphipoda	304	54.0	1107.2	35.2	3.6
Copepoda	235	41.7	506.3	16.1	2.2
Shrimps	45	8.0	109.5	3.5	2.4
Squid	14	2.5	39.1	1.2	2.8
Pteropoda	11	2.0	8.7	0.3	0.8
Chaetognatha	38	6.7	35.5	1.1	0.9

Group (1) FISH

Nine species of fish have been identified in the stomach contents, and the majority of the fish remains which could not be identified probably belong to one or other of these species, as on the occasions when fish were found in the stomachs they were usually of the same species throughout the sample. Of the fish identified the commonest species were the scaled lancet-fish, *Paralepis coregonoides borealis*, and the lanternfishes, *Myctophum punctatum* and *Benthosema glaciale*. On only one occasion were small redfish found in the stomachs and these were mixed with small cod and capelin. This sample came from shallower water than normal, approximately 80 fathoms (146 m) on the southwest edge of the Grand Bank. There has been one record of recently extruded larvae of redfish in the stomachs and one record of fish guts which had obviously been taken very shortly before capture.

Group (2) EUPHAUSIACEA

The three species comprising this group were found in approximately the same proportions. In general the euphausians found in any one sample of stomachs were either *Meganyctiphanes norvegica* or a mixture of *Thysanoessa inermis* and *Thysanoessa raschii*. No euphausians were found which were too damaged for identification and these three species comprise the group.

Group (3) AMPHIPODA

This group comprises a large proportion of the food of the redfish in this area and is composed of 5 species. Gammarid amphipods were found in very small numbers with less than 3% occurrence. Hyperiid amphipods were very abundant and the two species *Themisto libellula* and *Themisto gaudichaudi* were the most important, comprising 90% of all amphipods found in the stomachs.

Group (4) COPEPODA

Copepods also formed a large proportion of the food and the two most abundant species were *Calanus finmarchicus* and *Calanus hyperboreus*.

Group (5) SHRIMP

Shrimp formed 46% of the total volume of the food of redfish from the Gulf of St. Lawrence, and 17% in redfish from Trinity Bay. They were all of one species, *Pandalus borealis*.

Group (6) OTHER ORGANISMS

The organisms classed under this heading were not very abundant and were found only in a few samples. Pteropods occurred once, from a sample from the Gulf of St. Lawrence. Squid were found on 4 occasions but only in one of these

were they the main item of food and this sample came from deeper water than is normally fished. Chaetognaths were found on a number of occasions but never in appreciable quantities.

ANALYSIS OF THE STOMACH CONTENTS FROM DIFFERENT AREAS

The area from which the samples of stomachs were collected can be divided into 5 sub-areas.

(i) The Gulf of St. Lawrence (140–150 fath, 256–274 m)

(ii) The southwest edge of the Grand Bank (60–200 fath, 110–366 m)

(iii) The northern Grand Bank and Hamilton Inlet Bank (150–390 fath, 275–713 m)

(iv) Hermitage Bay and the south coast of Newfoundland (124–160 fath, 227–293 m)

(v) Trinity Bay (180–195 fath, 329–357 m).

The differences in the diet of the redfish from the 5 areas are summarized in Table III. The numbers of stomachs examined were insufficient for comparisons to be made at individual depths.

Gulf of St. Lawrence

This area is the only one in which shrimp have been found to be an important part of the food of the redfish and probably they take the place of fish, as the species of fish upon which the redfish normally feed are scarce in this area. Euphausians provide a large proportion of the food, and amphipods and copepods, although found in many stomachs, do not provide such a large part of the total volume of the food as they do in other areas.

Southwest Edge of the Grand Bank

In this area fish are by far the most important items of food in the diet with euphausians providing approximately one-third of the total volume of food. Amphipods and copepods were moderately abundant in occurrence though contributing very little to the total food supply.

Northern Grand Bank and Hamilton Inlet Bank

In this area while fish are still an important part of the food the predominant food group is that of the amphipods, with copepods being only slightly less important than fish. Euphausians have a percentage occurrence of 16%, 3% more than fish, but they contribute only 2% of the total volume of food. The

TABLE III. Differences in feeding of redfish from different areas.

Area	Number of undamaged redfish stomachs containing food	Percentage occurrence						Percentage of total volume of food						Average volume, in cubic centimetres					
		Fish	Euphausiacea	Amphipoda	Copepoda	Shrimp	Other organisms	Fish	Euphausiacea	Amphipoda	Copepoda	Shrimp	Other organsims	Fish	Euphausiacea	Amphipoda	Copepoda	Shrimp	Other organisms
Gulf of St. Lawrence	36	...	56	47	45	19	31	...	33	4	8	46	9	...	1.6	0.2	0.5	6.3	0.8
Southwest edge of Grand Bank	27	56	49	49	15	...	4	49	46	4	+	...	1	11.4	14.7	1.5	0.1	...	2.6
Northern Grand Bank and Hamilton Inlet Bank	346	13	16	72	72	...	15	26	2	47	22	...	3	12.9	0.6	4.3	1.9	...	1.4
Trinity Bay	25	...	60	92	4	16	...	...	23	60	+	17	...	...	0.7	1.2	0.1	1.9	...
Hermitage Bay and south coast of Newfoundland	129	1	92	2	5	11	...	2	90	+	1	7	...	4.8	2.4	0.1	0.5	1.8	...

hyperiid amphipods which provide the major part of the food of the redfish in this area are very abundant in the Labrador Current water and this is especially true of *Themisto libellula*.

Hermitage Bay and South Coast of Newfoundland

In the samples examined euphausians are the most important food supply of the redfish in this area, to the almost complete exclusion of other groups. They occur in 92% of the stomachs and provide 90% of the total volume of food Fish are rarely found and the amount of food provided by amphipods is negligible. Plankton samples from this area have shown that euphausians are very common but copepods and amphipods are also found in reasonable abundance. The samples of stomachs and plankton have been obtained in December, June and September. Euphausians predominated in the diet on each occasion. It is most likely that there is some selection of food by the redfish in this area as the amount of other food species in the stomach contents does not compare with the relative amounts of food in the plankton samples but further study is needed to confirm this.

Trinity Bay

In the samples examined the most important items in the diet were amphipods. They occur in 92% of the stomachs and make up 60% of the total volume of food.

CHANGES OF DIET RELATED TO THE SIZE OF THE FISH

It has been noted in studies on the food of many other fish that there is a change in the feeding habits as the size of the fish increases. The redfish from the Newfoundland area show a similar change (Table IV). The larger and older redfish tend to feed more on fish and the importance of Crustacea in their diet diminishes.

The percentage occurrence of the various food groups, except fish, remains fairly constant at the larger sizes but the amount of each group taken alters as the length of the fish increases. In the smaller size group (below 26 cm) fish do not appear in the diet at all and only to a small extent in the next two size groups (26–30 and 31–35 cm). In the next group (36–40 cm) fish are as important as amphipods and euphausians and in the case of the largest fish (above 40 cm) fish contribute 62% of the total volume of food.

The diet of the very small redfish in these samples consists mainly of euphausians but this is most probably due to the fact that the majority of the small redfish examined were taken in Hermitage Bay. In this area, as shown above, euphausians predominate in the food of redfish of all sizes.

TABLE IV. The food of redfish of different length groups.

Length range	Number of undamaged redfish stomachs containing food	Percentage occurrence						Percentage of total volume of food						Average volume, in cubic centimetres					
		Fish	Euphausiacea	Amphipoda	Copepoda	Shrimp	Other organisms	Fish	Euphausiacea	Amphipoda	Copepoda	Shrimp	Other organisms	Fish	Euphausiacea	Amphipoda	Copepoda	Shrimp	Other organisms
cm																			
Below 26	46	...	67	26	15	13	2	...	50	24	13	11	2	...	1.1	1.5	1.4	1.3	1.6
26 – 30	114	2	35	65	55	10	...	1	14	61	21	3	...	2.5	1.1	3.6	1.5	1.8	...
31 – 35	149	8	39	59	50	7	10	12	14	47	20	3	4	6.9	1.7	3.8	1.9	2.5	1.7
36 – 40	208	16	36	50	51	7	10	27	24	26	18	3	2	10.9	4.1	3.3	2.1	3.4	1.5
Above 40	45	30	20	55	43	2	10	62	7	23	4	2	2	25.1	4.1	5.0	1.1	7.6	1.8

DISCUSSION

From the analysis of the contents of these stomachs it is evident that the redfish is mainly a pelagic feeder. Most of the organisms found in the stomachs were pelagic and completely dissociated from the bottom and none could be regarded as completely benthic. Boldovsky (1944) reaches a similar conclusion with regard to the redfish in the Barents Sea. Steele (1957) states that pelagic forms made up over 90% of the volume of the contents of the stomachs of redfish from the western part of the Gulf of St. Lawrence. The fish which form the most important part of the diet of the larger redfish are all pelagic and some of them bathypelagic. It appears probable that the redfish comes up from the bottom to feed, possibly at night. There are differences in the feeding habits of redfish from different parts of the Newfoundland area which may be due to the differing numbers of the various food organisms present.

ACKNOWLEDGMENTS

The material for this study was obtained and the work carried out at the Fisheries Research Board of Canada Biological Station, St. John's, Newfoundland. I wish to thank Dr W. Templeman for his help and encouragement in preparing this paper, and also Mr E. J. Sandeman who collected much of the material at sea.

REFERENCES

BIGELOW, H. B., AND W. C. SCHROEDER. 1953. Fishes of the Gulf of Maine. *U.S. Fish and Wildlife Serv., Fish. Bull.*, **53**(74): 1–577.

BOLDOVSKY, G. V. 1944. [The food of the redfish in the Barents Sea.] *Trudy Poliarnovo N.-I. Inst. Morskovo Rybnovo Khoziaistva i Okeanografii*, **8**: 307–330. Murmansk.

MCINTYRE, A. D. 1952. The food of the halibut from North Atlantic fishery grounds. *Marine Res.*, **3**: 1–20.

STEELE, D. H. 1957. The redfish (*Sebastes marinus* L.) in the Western Gulf of St. Lawrence. *J. Fish. Res. Bd. Canada*, **14**(6): 899–924.

A Description of the Semi-buoyant Eggs and Early Developmental Stages of the Goldeye, *Hiodon alosoides* (Rafinesque)[1]

By Helen I. Battle[2] and William M. Sprules[3]

ABSTRACT

The goldeye in Canada occurs in large muddy rivers and associated lakes, being most abundant on the plains. Spawning usually occurs from late May to early July. In Lake Claire, Alberta, males reproduce first at 6–9 years of age and females at 7–10 years; in southern Manitoba first maturity averages 2 or 3 years earlier than this. Goldeye eggs were discovered in Lake Claire. They are bathypelagic or semi-buoyant, a characteristic which is rare among freshwater fishes. The egg is spherical, measures 4 mm in diameter, has a wide perivitelline space, coarsely granular yolk, and a large oil droplet. Prehatching developmental stages, including the multicellular blastoderm, the 41- and the 51-somite embryos, are described; as are the diagnostic characteristics of early larvae (7.27–7.63 mm), late larvae (11.8–15.6 mm), postlarval young fish (16.0–29 mm), and a 33 mm fish.

INTRODUCTION

The goldeye, *Hiodon alosoides* (Rafinesque), is widely distributed in Canadian fresh waters from the Quebec–Ontario boundary to the eastern slope of the Rocky Mountains and from the International Boundary, west of the Great Lakes, north to Great Bear Lake. Throughout its range it is found in large river systems and their associated lakes including the Severn, Red, Assiniboine, Saskatchewan, Churchill, Athabaska, Peace and Mackenzie Rivers, all characterized by muddy water caused by the presence of fine clay particles in suspension.

Smoked goldeye has gained an enviable reputation as a table delicacy and the demand for this product far exceeds the supply available from the commercial gill net fisheries of Lake Claire, Lake Winnipegosis, Lake Winnipeg, Sandy Lake and the Saskatchewan River. The commercial production, which was confined to Lake Winnipeg and Lake Winnipegosis during the early years of the fishery, reached a peak between 1926 and 1929 when more than one million pounds were taken annually. The catch declined steadily to less than 80,000 pounds by 1946 and then increased to about 300,000 pounds annually with the development of new fisheries in Lake Claire, Alberta, and Sandy Lake, Ontario. In addition to its value as a commercial species, the goldeye is also of some interest to sport fishermen using surface lures and light tackle.

[1]Received for publication January 14, 1960.

[2]Professor of Zoology, University of Western Ontario, London, Ontario.

[3]Special Assistant to the Deputy Minister of Fisheries, Department of Fisheries, Ottawa. Formerly Biologist, Fisheries Research Board of Canada, Central Fisheries Research Station, Winnipeg, Manitoba.

J. Fish. Res. Bd. Canada, 17(2), 1960.
Printed in Canada.

The serious decline in the commercial production coupled with the paucity of published papers dealing with goldeye pointed to the need for a comprehensive study to provide essential data on which to base scientific management of this important resource. An investigation of the life history and habits of the goldeye was begun in 1945 and was terminated in the spring of 1949 when knowledge of the life history was completed with discovery of the semi-buoyant or bathypelagic nature of the eggs. During the first years of the investigation, although ripe females were taken regularly in gill nets and small juveniles were obtained by seining, all efforts to obtain eggs or larvae by means of bottom drags and dredging proved unsuccessful. The first indication that the eggs of the goldeye were semi-buoyant was obtained during the spawning period in the spring of 1948 when what were thought to be goldeye eggs were found in windrows along the shore and suspended in shallow inshore waters of Lake Claire in northern Alberta. In the spring of 1949 a collection of eggs and larvae was made at Lake Claire and Lake Mamawi using a fine-mesh drag operated in surface waters.

LITERATURE REVIEW

Although the eggs of many marine fishes are buoyant or pelagic, there are few freshwater species for which this condition has been recorded. McIntosh and Masterman (1897) investigated the life histories of 72 British marine food fishes representing 21 families. They listed 48 species with pelagic eggs and 24 with demersal; the nature of 3 of the pelagic and 4 of the demersal types was not definitely established. A Manual of Fish Culture (1898) records the characteristics of eggs of 52 species belonging to 19 families of North American fishes. Fifteen marine species are reported to have buoyant eggs and 3 to have heavy ones. The remaining species are freshwater and anadromous forms, 27 of which produce heavy eggs, 5 semi-buoyant (i.e. eggs with a specific gravity slightly greater than that of water) and 2 non-adhesive buoyant ones. The species listed with semi-buoyant eggs include: the whitefish, *Coregonus clupeaformis*; the lake herring, *Coregonus artedii artedii*; the longjaw whitefish, *Coregonus nigripinnis prognathus*; the shad, *Alosa sapidissima*; and the muskellunge, *Esox masquinongy masquinongy*. Those with buoyant non-adhesive eggs are the striped bass, *Roccus lineatus* (=*Roccus saxatilis*), and the white perch, *Morone americana*.

Ehrenbaum (1905, 1909), describing the eggs of fish representing 38 families from European waters, included all species previously reported by McIntosh and Masterman (1897); 9 of the families had one or more freshwater, brackish or anadromous species. Of the marine species 62 were recorded as depositing pelagic eggs; the nature of the eggs of 3 species was not definitely determined. Those of the grenadier, *Coelorhynchus carminatus*, were described as being initially pelagic, but in later developmental stages as descending to depths of 80 to 100 metres. Forty marine species were indicated as having demersal eggs; the characteristics of 3 of these were questionable, since they were assumed to be demersal on the basis of comparison with closely allied species, or through lack of evidence of a planktonic nature. Of the species depositing eggs in fresh or brackish water, 15 were recorded as demersal and 6 as semi-buoyant. Eggs of the burbot, *Lota vulgaris*, the shad, *Alosa sapidissima*, and the northern pike, *Esox lucius*, float free either near or on the bottom, although those of the last-named species initially appear to be adhesive. Eggs of the seaperch, *Roccus labrax*, were referred to as pelagic when deposited in salt water, and as demersal in freshwater; those of the argentine, *Argentina silus*, which rarely occur at the surface, as buoyant at depths of 50 to 100 metres; and those of *Argentina sphyraena*, as suspended at "moderate" depths and occasionally appearing in surface active waters. Leach (1923) described the eggs of the Montana grayling, *Thymallus montanus* (=*Thymallus arcticus*), as semi-buoyant because of the presence of a large oil globule.

Fish (1932) reported heavy eggs for 18 species of freshwater fishes representing 9 families from Lake Erie. Brinley (1938) has presented in tabular form the characteristics of the eggs of various North American fishes: of 31 marine species representing 16 families, 23 have pelagic eggs, and 8 demersal; all 32 fresh or brackish water and anadromous species from 13 families were classified as having demersal eggs.

Bigelow and Schroeder (1953) recorded the characteristics of the eggs of marine fishes of the Gulf of Maine representing 38 families of which 29 species have a pelagic type and 18 a demersal; the nature of eggs of 8 additional species in each group is doubtful or based on reference to corresponding European species. Of the 9 anadromous species listed, only the shad, *Alosa sapidissima*, and the striped bass, *Roccus saxatilis*, are semi-buoyant, the remainder being demersal.

Stenger (1956) in a key to the eggs of Passamaquoddy Bay, New Brunswick, lists the striped bass, *Roccus saxatilis*, and the shad, *Alosa sapidissima*, among species having bouyant or semi-buoyant eggs; and the alewife, *Pomolobus pseudoharengus*, the blueback, *Pomolobus aestivalis*, the salmon, *Salmo salar*, the smelt, *Osmerus mordax*, and the white perch, *Morone americana*, as demersal in type.

It is apparent from this brief review that most freshwater fishes reported from temperate regions produce heavy eggs which sink to the bottom immediately after extrusion. A few species, however, have semi-buoyant eggs which are only slightly heavier than water and which would presumably assume a pelagic nature providing the water is in motion. This could account for the apparent discrepancies in the literature pertaining to some species. McIntosh and Masterman (1897) state "eggs of the shad, *Alosa sapidissima*, are slightly heavier than the water, so that they remain in suspension near the bottom". A Manual of Fish Culture (1898) lists the shad, *A. sapidissima*, in a summary table as a species with semi-buoyant eggs, while in the text proper the authors state "after being extruded, the eggs sink to the bottom where they remain until hatched". Ehrenbaum (1909) refers to the shads, *Alosa sapidissima* and *Clupea finta*, as bathypelagic. Leim (1924) indicated that eggs of *A. sapidissima* sink, while Bigelow and Schroeder (1953) state that this species has semi-buoyant eggs which "roll about on the bottom with the current". Although A Manual of Fish Culture records semi-buoyant eggs for the lake herring, Fish (1932) states that the eggs of the lake herring "incubate on the bottom during the long winter months". Whitefish and cisco eggs do fall slowly to the bottom of hatchery jars unless the water is agitated. Eggs of the muskellunge, *Esox masquinongy*, white perch and striped bass are probably of the same type. Pearson (1938) states that the eggs of the striped bass, *Roccus saxatilis*, an anadromous species, are "slightly heavier than fresh water and sink to the bottom of unagitated water. However, a slight movement of the water serves to float the eggs and keep them in suspension". Merriman (1941) refers to them as semi-buoyant, and Mansueti (1958) found them to be pelagic and buoyant, although sinking in quiet fresh water. Moore (1944) reported that although the eggs of the Arkansas river shiner, *Notropis girardi*, are carried in currents, they sink in still water. Davis (1959) recently collected the eggs of the sheepshead, *Aplodinotus grunniens*, in surface plankton tows at the west end of Lake Erie. He has described them as pelagic throughout development.

The eggs of the yellow perch, *Perca flavescens*, are reported to be semi-buoyant by Webster (1942) but they represent a different type since they are extended in an elongate mass and do not develop separately in the water. A Manual of Fish Culture (1898) describes them as semi-buoyant in the text, but lists them as heavy in the summary table.

The gouramies or labyrinthic freshwater fishes of Asia and Africa produce floating eggs (Kyle, 1926). Moorkerjee (1945) records floating (as contrasted to non-floating, non-adhesive or adhesive) eggs for 6 freshwater species in India: *Ophicephalus punctatus*, *O. striatus*, *O. marulius*, *Anabas testudineus*, *Colisa fasciata* and *Colisa lalius*. Five freshwater Indo-Pacific species with pelagic or buoyant eggs are listed by Hora and Pillay (1955): the kissing gourami, *Helostoma temmincki*, the climbing perch, *Anabas testudineus*, and three nest builders, the sepat siam, *Trichogaster pectoralis*, the sepat djawa, *T. trichopterus* and the gourami, *Osphronemus goramy*. Eggs

of the nilem, *Ostechilus hasselti*, are referred to as semi-buoyant, and those of the grey mullet, *Mugil corsula*, which also occurs in estuarine and coastal waters, as both pelagic and semi-buoyant.

MATURITY AND SPAWNING

In Canadian waters goldeye begin to spawn in the spring shortly after the winter ice cover leaves the lakes and rivers. The length of the spawning period is related to the water temperatures prevailing in the shallow inshore spawning areas and normally extends from late May to the first week of July.

Males reach maturity one year earlier than females and the age at maturity tends to decrease from north to south throughout the geographic range of the goldeye. In Lake Claire, Alberta, males reached maturity between 6 and 9 years of age and females reached maturity between 7 and 10 years. In southern Manitoba the age at maturity is advanced 2 or 3 years and may be further advanced in the southern part of its range in the United States. Sexual dimorphism occurs in goldeye with the anterior rays of the anal fin of the male becoming elongated to form a distinct lobe as the first spawning season is approached. The anal fins of immature goldeye of both sexes, and of mature females, do not possess such a lobe.

It is possible to separate the sexes quite readily after the first year of growth by the appearance of the testes and ovaries. The immature testis appears as a narrow unstriated band which enlarges with age and becomes convoluted as the first spawning season approaches. The ripe testis assumes a red hue and the milt appears as white islands throughout the posterior, heavily convoluted portion of the testis. The immature ovary appears as a wider, vertically striated band with small white eggs becoming apparent as the first year of maturity approaches. The ovaries enlarge to fill the body cavity prior to spawning and at this time the eggs average 2.0 mm in diameter. The number of eggs produced varies with the age and size of the individual female but is not a linear function of these factors. The average number of eggs in 15 females from several lakes in Manitoba was 14,150 with a range from 5,800 to 25,200. The specimens sampled ranged from 7 to 13 years in age, from 13 to 28 ounces (370–800 g) in round weight and from 12 to 15½ inches (30–40 cm) in fork length.

EMBRYONIC DEVELOPMENT

Characteristics of the Egg

Source: Mouth of Prairie River, Lake Mamawi, June 7, 1949.

The spherical eggs are free-floating at some depth and may be referred to as bathyplanktonic or semi-buoyant. The capsule is apparently of a non-adhesive nature, since there was no evidence of adherence of the eggs to one another nor was there any accumulation of foreign particles on the surface. Most of the

preserved material was somewhat distorted and shrunken because of unfavourable fixation and the following measurements are based on the averages of four of the least distorted eggs:

Diameter	4.0 mm
Diameter of yolk sphere parallel to embryonic axis	2.4 mm
The same, vertical to the axis at mid-body level	2.1 mm
Width of perivitelline space (decreasing in width as development progresses)	0.90 to 1.0 mm
Diameter of oil globule	0.67 to 0.95 mm

The egg capsule or chorion (Fig. 1) is semi-transparent and perforated by small pores located at the tip of tiny elevations spaced from 8 to 10 microns apart. The yolk is cream-coloured and consists of coarsely granular spheres varying in diameter from 5 to 40 microns (Fig. 2). The smaller spheres appear to be more peripherally located in the yolk mass. The large oil globule is single and situated near the surface of the yolk. It showed considerable variation in shape which could be a distortion consequent upon fixation, since it would presumably be spherical in the living egg.

The wide perivitelline space is no doubt related to the semi-buoyancy of the egg and serves as a protective mechanism for the embryo. It is characteristic of a few buoyant eggs such as *Hippoglossoides platessoides* (Bigelow and Schroeder, 1953), *Hippoglossus vulgaris* (Ehrenbaum, 1905), *Drepanopsetta platessoides*

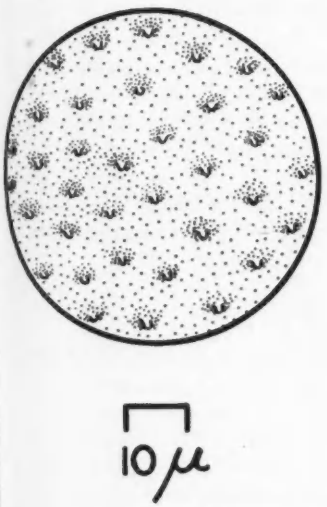

FIG. 1. Surface view of egg capsule (chorion). Distance between pores, 8–10 microns.

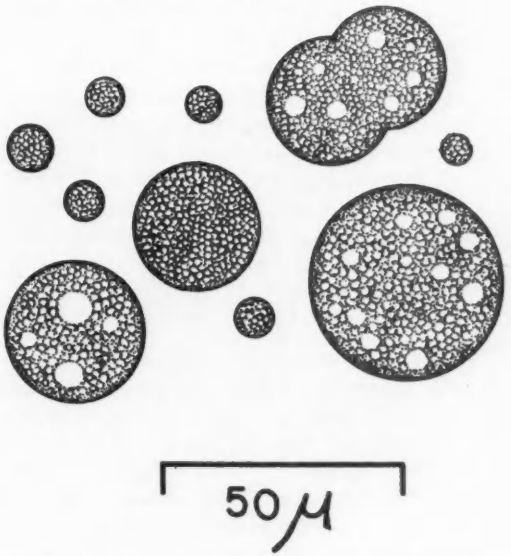

FIG. 2. Typical yolk granules. Diameters 5–40 microns.

(McIntosh and Masterman, 1897; Ehrenbaum, 1905), *Conger niger* (Ehrenbaum, 1909), *Clupea pilchardus* (McIntosh and Masterman, 1897), *Brevoortia tyrannus* (Bigelow and Schroeder, 1953) and *Aplodinotus grunniens* (Davis, 1959). However, such a space is also evident in certain demersal eggs, notably: *Stizostedion vitreum* (Reighard, 1890), *Pomolobus aestivalis* (Kuntz, 1916; Bigelow and Schroeder, 1953), *Notropis cornutus chrysocephalus* (Fish, 1932), *Coregonus clupeaformis* (Fish, 1932; Price, 1934) and *Cyprinodon variegatus* (Kuntz, 1916). It is more common among the relatively few semi-buoyant eggs recorded: *Alosa sapidissima* (McIntosh and Masterman, 1897; Bigelow and Schroeder, 1953), *Clupea finta* (McIntosh and Masterman, 1897) and *Roccus saxatilis* (Merriman, 1941; Mansueti, 1958). Ehrenbaum (1909) indicated that the perivitelline space is somewhat wide in the egg of *Lota vulgaris* which lies on the bottom or floats near it.

Prehatching Developmental Stages

Three stages only will be described here, representing specimens which were sufficiently well preserved to warrant detailed examination.

(i) *Multicellular Blastoderm* (Fig. 3)

The blastoderm measuring 1.3 mm in diameter appears as a cap on the surface of the yolk. The thickened margin is indicative of the initiation of involution around the germ ring. The oil globule is eccentrically located beneath the blastoderm but is not at the immediate surface of the yolk sphere. In typical buoyant eggs with small or moderate sized oil droplets such as those of the sea bass, *Centropristes striatus* (Wilson, 1891), and the four-bearded rockling, *Enchelyopus cimbrius* (Battle, 1929), the embryo develops at the lower pole of the egg, and the oil globule lies in the upper surface of the yolk. In eggs containing large oil globules such as those of the pike-perch, *Stizostedion vitreum* (Reighard, 1890), and the striped bass, *Roccus saxatilis* (Merriman, 1941; Mansueti, 1958), the blastodisc appears on the surface of the yolk sphere at approximately a 90° angle to the horizontal. This may conceivably hold true for the goldeye also, since the oil globule in the few specimens available was in an eccentric position with reference to the blastoderm.

(ii) *41-Somite Embryo* (Fig. 4, 5)

The blastopore has closed at this stage following complete overgrowth of the yolk sphere by the blastoderm. The oil globule is ventrally and somewhat anteriorly located in the yolk sac, indicative of its future permanent location. The embryonic axis extends around approximately two-thirds of the circumference of the yolk sphere. It is adherent to the yolk sac anteriorly and posteriorly with the exception of the anlage of the tail just caudal to the anal region. A narrow median fin fold outlining the margin of the tail extends anteriorly along the dorsal line to the mid-level of the body. The 41 muscle somites are regularly chevron-shaped. The notochord appears as a vacuolated rod extending from

FIG. 3. Late multicellular blastoderm prior to epiboly.

FIG. 4. 41-somite embryo, ventral view.

FIG. 5. 41-somite embryo, lateral view.

FIG. 6. 51-somite embryo, lateral view.

the level of the thick-walled auditory vesicle to the tip of the tail. The brain is composed of three primary divisions, the mesencephalon being especially prominent. The rhombencephalon is considerably elongated and the IVth ventricle is diamond-shaped. The optic vesicle has invaginated in the form of a cup into which the lens has already sunken. The olfactory placodes are invaginating. The primordium of the heart has made its initial appearance. No pigmentation is apparent at this stage.

(iii) *51-Somite Embryo* (Fig. 6, Table I)

The embryonic axis has elongated while the head has extended forward from the yolk sac and the caudal region is free to a level 10 somites anterior to the anus. No pigment is apparent. The brain has increased in size and differentiation over that of the 41-somite embryo. The otic vesicle has enlarged and is very thick-walled. Primordia of 3 gill arches are evident. The yolk sac itself is somewhat spherical and the oil globule has assumed a more anterior position. The alimentary canal lying on the dorsal surface of the yolk passes posteriorly to the level of the anal plate, which is not yet patent. The median dorsal fin fold extends from the somewhat expanded tail fin forward to the head region.

Larvae and Young Fishes

Table I is a résumé of the length measurements of prehatching embryos early and late larvae and postlarval young fish.

(i) *7.27 to 7.63 mm. Early Larvae or Prolarvae* (Fig. 7)

Source: Whiteshell Troughs, June 12, 1949.

Because of the large size of the yolk sac, which has a maximum length of 2.17 mm and maximum depth of 1.50 mm, it may be assumed that these larvae are in the immediate posthatching condition. The large oil globule occupies an extensive portion of the yolk sac, and lies immediately posterior to the heart. The newly hatched larvae were observed floating in a vertical position at the water surface with the head uppermost, in all probability because of the buoyant effect of the oil globule. Ehrenbaum, (1905, 1909) illustrates the oil globule in larvae of some 62 species of marine and freshwater fishes. In 26 species it occurs in a posterior position, while in 23 it occupies an anterior position corresponding to that of the goldeye. In two of the latter species, *Lota vulgaris* and *Argentina silus*, the eggs are semi-buoyant. Merriman (1941) and Mansueti (1958) have indicated a similar location for the oil globule in the semi-buoyant egg of the striped bass, *Roccus saxatilis*, and Reighard (1890) for the freshwater species, *Stizostedion vitreum*, with a demersal egg. On hatching, the latter investigator states that "owing to the lightness of the oil globule, it together with the yolk, is always turned uppermost during early movements, so that the embryo swims on its back. It is only when the pectoral fins have become sufficiently developed

TABLE I. Measurements and meristic characters of prehatching embryos, larvae and postlarval young stages of the goldeye. Measurements are in millimetres. Length range and average length are from the tip of the snout to the end of the middle part of the caudal fin fold or the middle rays of the tail (*median* or *fork* length).

	Prehatching embryo	Early larvae	Late larvae		Postlarval young fish				
Length range	4.80	7.27–7.73	11.8–13.5	15.0–15.6	16.0–17.1	19.0–21.0	24.0–25.5	28.0–29.0	33.0
Number of specimens	3	5	10	10	5	5	10	5	1
Average length	4.80	7.49	12.8	15.4	16.7	19.8	24.8	28.6	33.0
Standard length	4.70	7.19	12.2	14.7	15.7	18.5	22.8	26.0	28.5
Length to vent	3.50	4.50	7.70	9.18	10.8	11.8	13.8	15.8	18.0
Length to head	0.75	1.10	2.46	3.07	3.40	4.26	5.36	6.28	7.40
Snout	0.12	0.30	0.58	0.79	0.86	0.95	1.23	1.68	1.90
Diameter of eye	0.27	0.33	0.67	0.97	1.14	1.35	1.61	1.88	2.20
Greatest depth before vent	1.70	2.26	1.70	2.35	2.62	3.40	4.76	5.28	6.80
Depth behind vent	0.35	0.67	0.84	1.25	1.64	2.10	3.37	4.72	5.60
Myomeres to vent	26	28–29	29+	30	30	30	30	30	30
Myomeres behind vent	25+	31–32	29+3	29+3	29+3	29+3	29+3	29+3	29+3
Fins:									
continuous dorso-ventral fold	*	*	...	...	...	...	...	...	...
dorsal radials	...	...	9	9–10	10	10–12	12	12	12
dorsal rays	...	...	0	0–3	7–8	10	10	10	10
caudal hypurals	...	...	5	6–7	8	9	10	12	13
caudal rays	...	...	9–12	12–15	17–20	20	20	20	21
anal radials	...	...	21–23	22–24	27	34–35	34–35	35–36	38
anal rays	...	...	0	0	18–21	30–32	32–34	32–34	35
pectoral rays	...	*	0–1	3–5	8	10	11–12	11–12	12
pelvic rays	...	...	...	...	...	*	0–2	0–3	5
maximum depth ventral fin fold	0.08	0.34	0.45	0.70	1.00	1.10	1.50	1.40	1.15

+Indicates incomplete somites occurring dorsal to tip of notochord or urostyle.
*Indicates primordia of fins.

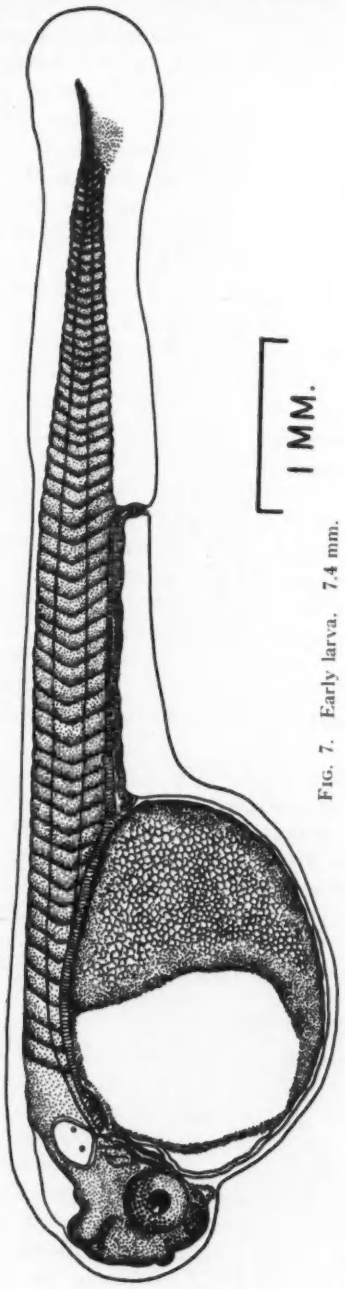

FIG. 7. Early larva. 7.4 mm.

to be of use that the fish is able to keep its back uppermost". Fish (1932) illustrates an anteriorly located oil globule in the following species of freshwater fish: *Hiodon tergisus, Coregonus artedii, Coregonus clupeaformis, Notropis hudsonius, Notropis cornutus chrysocephalus, Perca flavescens, Stizostedion vitreum, Etheostoma nigrum nigrum.* The position of the oil globule may vary even in forms with similar eggs. Hildebrand and Cable (1930) indicate that in the pigfish, *Orthopristis chrysopterus*, the oil globule occupies the anterior margin of the yolk sac under the head; whereas in the white perch, *Roccus americanus*, it is in a posterior position on the ventral surface of the trunk.

The larval head at this stage is rather strongly deflected into the yolk sac, but the body axis is straight with the posterior tip of the notochord only inclined slightly dorsally. The gut is clearly evident as a straight tube and the anus is almost patent. The somites display a regularly chevron-shaped pattern. The pectoral fin, located immediately ventral to the auditory vesicle, appears as a fleshy fold 0.25 mm in length, without dermal rays. The pigmentation, when apparent, is confined to spherical melanophores in the dorso-lateral region of the iris. The median marginal fin fold is slightly elevated just posterior to the anus, indicative of the future location of the anterior margin of the dorsal fin. It extends around the tail as the caudal fin and passes forward where it is again slightly elevated in the region of the future anal fin.

There is evidence of the future stomodaeal region at the tip of the snout which now rests on the anterior face of the yolk sac. The heart is a straight tube and 3 gill arches are apparent. The choroid fissure of the eye has been obliterated by fusion of the ventral margins of the optic cup. The ovoid auditory vesicle is somewhat thinner-walled than in the prehatching embryo and contains 2 otoliths.

The larva at this stage shows certain similarities to that of the mooneye, *Hiodon tergisus*, at 6.5 mm as illustrated by Fish (1932), but it is considerably less advanced in many respects. In the mooneye, the blunt terminal mouth is open, the pectoral fins are well developed although unrayed, and the dorsal marginal fin fold is more distinctly elevated. The caudal fin is smaller than that of the goldeye and dermal rays are developing ventral to the notochord.

(ii) *11.8 to 13.5 mm. Late Larva* (Fig. 8)

Source: Lake Claire, June 11, 1948.

This late larval stage differs from the early larva in several ways. The yolk sac has been considerably reduced in size and now has a length of 0.90 to 1.0 mm and a depth of 0.8 to 0.9 mm. The oil globule occupies approximately one-half of the volume of the sac and, while usually in an anterior location it occasionally may assume other positions. In two instances it was resting on the posterior margin of the yolk immediately anterior to the liver. This shift in position could conceivably be an artifact representing a postmortem effect of fixation.

The body is slender, the nose blunt and protruding and the mouth is slightly inferior, with the gape to the distal margin of the pupil. The head is now

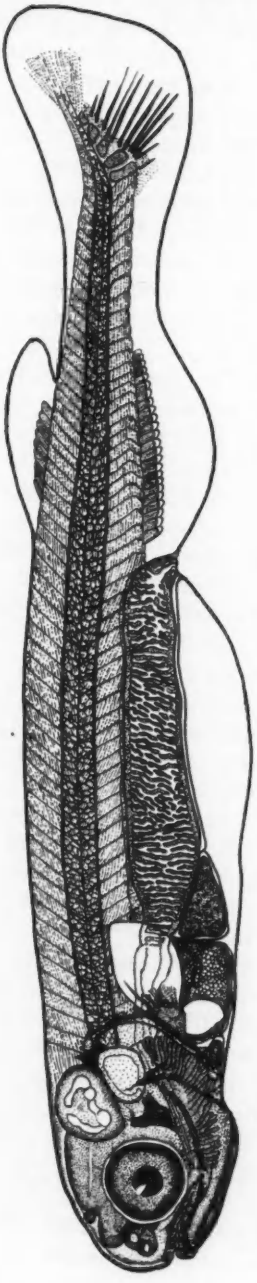

FIG. 8. Late larva. 11.8 mm. (Semi-transparency.)

directed anteriorly, not ventrally as in the early larva. The nostrils are large and relatively close together. Each nostril is divided into two chambers by a semi-spiral fold of tissue extending from the lateral toward the medial margin. The semicircular canals have developed in the otic vesicles which now measure 0.65 mm in length and 0.55 mm in depth.

The median dorsal fin fold is represented by the dorsal fin whose anterior margin is approximately at the level of the 30th somite. Nine radials are evident but no dermal rays have appeared. The 9 to 12 dermal rays supporting the caudal fin are all hypochordal and radiate from the 5 cartilaginous hypurals which lie beneath the dorsally directed tip of the notochord. The anal fin is differentiating and separated from the caudal by a slight constriction in the ventral fin fold. Radials (21–23), only, have developed. The median ventral fin fold extends from the anus to the heart region. The pectoral fins are fairly well developed, but in only one instance was a dermal ray apparent. The last 3 somites of the tail region are incomplete and are apparently represented ventrally by a dense connective tissue covering the hypurals.

The digestive tract is now a straight tube showing some regional differentiation. An enlargement immediately posterior to the yolk sac is the anlage of the stomach. Cleared specimens showed a variety of food in tracts, including small crustaceans, crustacean eggs and diatoms. The liver in profile appears triangular with its anterior face abutting upon the posterior surface of the yolk sac. The gills are finely filamentous.

Specimens stained with alizarin-red S and cleared, indicated that although ossification of the vertebral column has not yet commenced, it has progressed a considerable degree in the slender cleithrum, premaxilla, the maxilla, the heavy dentary, vomer, parasphenoid, basihyal, hypohyal, opercle, and 2 to 3 branchiostegals. Widely set and sharply pointed teeth are ankylosed to the premaxilla, dentary, vomer and basihyal but have not yet protruded through the epidermis.

Pigmentation is still limited to the iris of the eye which is now dense and appears iridescent. Occasional exceptions occur, however, where discrete melanophores appear on the mid-dorsal surface of the head between the eyes and between the radials of the anal fin.

Expanded membranous vesicles have developed along the posterior ventral surface of each auditory vesicle. They are 0.5 mm in length and 0.4 mm in depth, and have walls about 0.05 mm in thickness. These vesicles represent anterior precoelomic diverticula of the swim bladder proper. The latter is now sometimes distinguishable as a narrow cellular mass dorsal to the digestive tract and extending from the gill region to the mid level of the liver. Precoelomic diverticula of this type have been described by Tracy (1920) for *Alosa sapidissma* and by Rauther and Leiner (1937) for *Gymnarchus niloticus*.

The 11.8- to 13.5-mm late larvae bear some resemblance to the 14.2-mm specimen of *Hiodon tergisus* described by Fish (1932). In both species the body is slender, the snout blunt, the mouth inferior, the premaxillaries and the maxil-

laries very slender, the gape of the mouth extends to the distal margin of the pupil, the teeth are wide set and the nostrils large and close together. They differ chiefly in that anal rays and more extensive pigmentation occur in the mooneye. In the illustrations by Fish, the remnant of the yolk sac is indicated in the 14.2-mm specimen of *H. tergisus* although it is lacking in the 6.5-mm specimen. Precoelomic diverticula of the swim bladder are not indicated in the 14.2-mm mooneye, but the somewhat inflated main swim bladder is considerably posterior to that found in the goldeye at this stage.

(iii) *15.0 to 15.6 mm. Late Larva*

Source: Lake Claire, Point de Roche, June 14, 1948.

These late larvae are very similar to the 11.8- to 13.5-mm stages except that the yolk sac has been further depleted and is now represented by a tiny oil droplet or a spherical mass of yolk granules resting on the anterior face of the liver. In a few instances the yolk sac has entirely disappeared and the larva may be considered as a postlarval young fish. The dorsal fin may have developed up to 3 dermal rays although none were noted in the anal, which has become more definitely delineated from the caudal fin. Teeth have appeared on the maxilla, otherwise ossification is not markedly greater than the preceding stage except for as many as 5 branchiostegals. Pigmentation is still largely limited to the iris of the eye with the exception of a few widely spaced melanophores on the dorsal surface of the head between the eyes. Occasionally a sinistral flexure has been initiated in the digestive tract immediately posterior and dorsal to the liver, and is indicative of the future stomach region.

(iv) *16.0 to 17.1 mm. Postlarval Young Fish* (Fig. 9)

Source: Lake Claire, Spruce and Beaver Point, June 19, 1948.

The young fish at this stage is still slender; the head region abrupt; the fins well delineated with the median ventral fold from the anus to the heart region increasing in depth over that in the late larval stages. The dorsal and anal fins possess 7 to 8 and 18 to 21 dermal rays respectively. The hypochordal dermal rays (17 to 20) in the caudal fin possess a single joint. No epichordal rays are present but the tail fin itself is more symmetrical than in the larvae and almost straight along its vertical margin.

The sinistral flexure of the digestive tract commenced in the previous stage has progressed so that the pyloric stomach is now directed anteriorly and extends into the ascending limb of the intestine forming an almost perfect U. A second sharp dextral flexure directs the small intestine posteriorly whence it passes as a straight tube to the anus. Rotation of the pyloric limb ventrally now leaves the cardiac stomach on the right of the mid dorsal line and the descending limb of the intestine on the left.

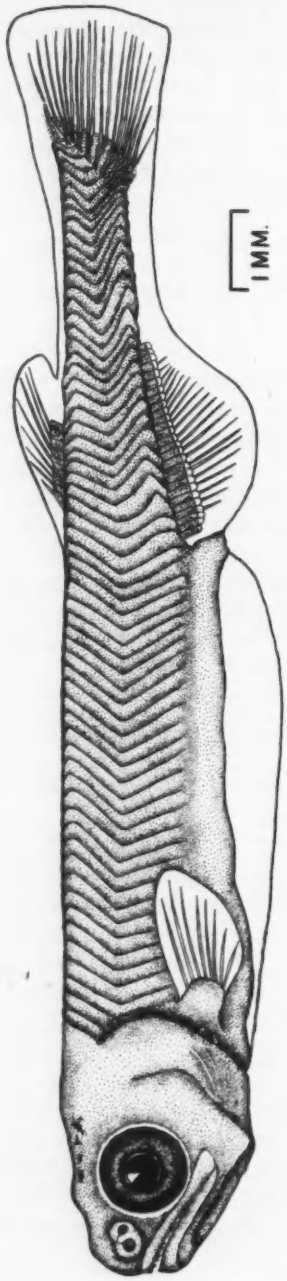

FIG. 9. Postlarval young fish. 16 mm.

Superficial melanophores have become more numerous on the head at the level of the mesencephalon. Much contracted melanophores occur deep within the auditory vesicle, around the lower margin of the eye, in the nostril and on the ventral surface of the notochord from the anterior level of the anal fin to the base of the caudal. A few melanophores may also appear among the radials of the anal fin.

(v) *19.0 to 21.0 mm.* *Postlarval Young Fish* (Fig. 10)

Source: Lake Claire, Mouth of the Hay River, June 25, 1948.

Postlarval young fish of this length show several distinct changes from the preceding stage. Primarily, the pelvic fins have appeared as outgrowths of the ventral body wall in the form of fleshy flaps on either side of the median ventral fin fold, about three-quarters of the distance from the tip of the snout to the anus and at the level of the 16th to 18th somites. The increase in the flexion and the torsion of the digestive tract combined with an increase in the diameter of the cardiac stomach is indicated by an expansion of the ventral body wall immediately below the pectoral fin. The median fin fold is correspondingly reduced at this level.

The hypurals show indications of division into a dorsal and ventral group and there is a slight median indentation in the posterior margin of the caudal fin. The hypochordal dermal rays now possess 3 or 4 segments. The anlagen of a few embryonic epichordal rays have appeared. The anal fin is now distinct from the caudal fin.

Superficial melanophores have increased in number. They are scattered at the anterior tip of the snout; a few occur along the margin of the lower jaw; and a single row is present on the ventral posterior margin of the eye. Widely expanded melanophores occupy a roughly quadrangular area over the mesencephalon; and thence extend in irregularly double rows on either side of the middorsal line from the head to the base of the caudal fin, where they concentrate in both the posterior remnant of the median dorsal fin fold and near the ascending tip of the notochord. A few occur along the lateral line from the level of the pectoral fin to the base of the caudal; one or two rows are present near the base of the radials of the anal fin. Internally, pigment is present along the dorsal and ventral surfaces of the notochord from the level of the pectoral fins to the terminal dorsal flexure. Other scattered melanophores appear along the middorsal line of the peritoneal cavity, around the auditory vesicles and the anterior membranous vesicles of the swim bladder.

Ossification has occurred in the neural and haemal arches of the vertebrae and extensively in the skull, the operculum and the pectoral girdle. Eight branchiostegals are evident. The teeth on the premaxillary, maxillary and dentary have penetrated through the epidermis.

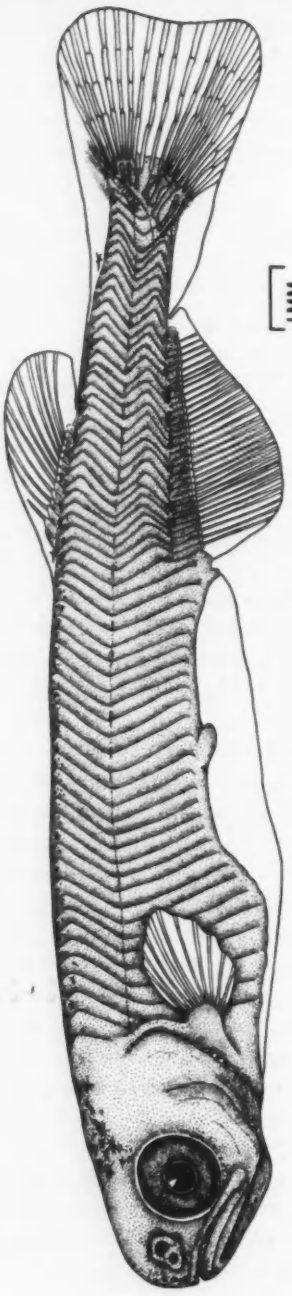

FIG. 10. Postlarval young fish. 20 mm.

(vi) *24.0 to 25.5 and 28.0 to 29.0 mm. Postlarval Young Fish*

Source: Lake Claire, Mouth of the Hay River, June 29, 1948.

Aside from increase in size and intensification of pigmentation in the regions enumerated in the 19.0- to 21.0-mm specimens, there are few major changes during this period. One of the most obvious is the decrease in depth of the median ventral fin fold from 1.50 mm in the 24.0–25.5 mm group, to 1.40 mm for the 28.0–29.0 mm group. Dermal rays make their appearance in the pelvic fins. The hypurals become definitely divided into a dorsal and a ventral group. The median notch in the caudal fin becomes more pronounced. Several delicate embryonic epichordal rays appear. The original hypochordal rays have now 4 to 5 segments and a few embryonic rays are appearing ventrally corresponding to the delicate dorsal epichordals.

(vii) *33.0 mm. Young Fish* (Fig. 11)

Source: Lake Claire, Mouth of the Hay River, June 29, 1948.

The young fish at this stage has assumed the more characteristic appearance of the goldeye including the blunt nose, terminal mouth and general body contour with the marked ventral keel. The dorsal, anal and caudal fins are now discreet. The median ventral fin fold has become considerably narrower. The caudal fin is distinctly forked. The hypurals are divisible into two groups, a ventral one composed of 6 and a dorsal composed of 7. The dermal fin rays are occasionally forked at their tips and composed of 5 to 7 segments. A number of fin epichordal and hypochordal rays are symmetrically disposed anterior to the typical dermal rays.

Melanophores produce a heavy pigmentation over the tip of both the lower and upper jaws, occasionally within the nostril, and over the skin of the margin of the lower surface of the eye. The mass over the dorsal surface of the head between the two eyes has become denser. Stellate melanophores intermingled with contracted ones occur in irregular rows from the head to the caudal fin. They extend ventrally on either side of the mid-dorsal line slightly less than midway to the lateral line. This dorsal band becomes progressively narrower from the posterior level of the dorsal fin to the base of the caudal fin. Superficial elongated melanophores mark the location of the lateral line. They also occur among the radials of the dorsal fin as well as at the base of those of the anal fin and among the dermal rays of the caudal fin.

GROWTH DURING THE FIRST YEAR

Growth is rapid during the first summer and as would be expected the size attained by underyearlings differs from year to year in one locality and from one locality to another dependent on the time of hatching and environmental conditions prevailing during the first growing season (Table II).

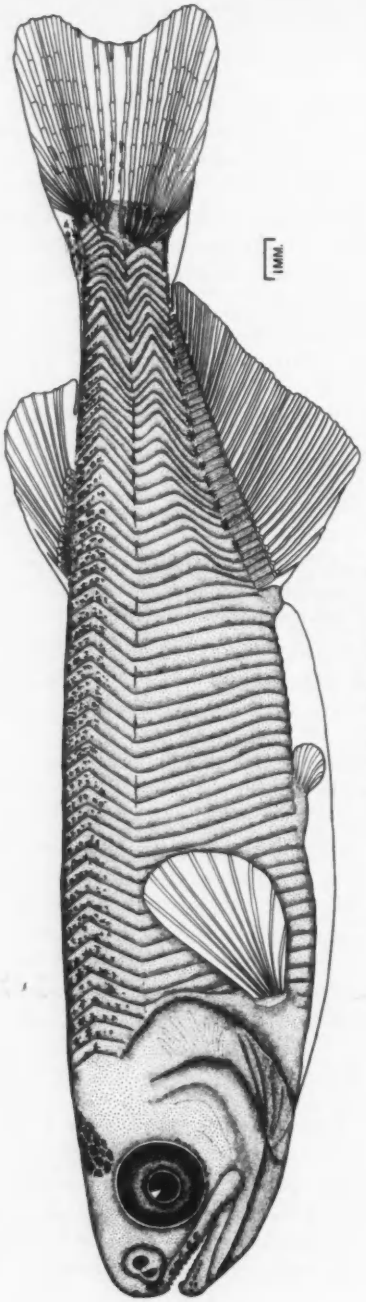

FIG. 11. Young fish. 33 mm.

TABLE II. The average length and weight of representative samples of underyearling goldeye from various localities.

Locality	Year	Day	Number of specimens	Average weight	Fork length Range	Fork length Average
			no.	*grams*	*mm*	*mm*
Lake Claire, Alta.	1947	July 14	35	0.1	23–30	26.5
	1947	July 17	5	0.1	25–30	27.2
	1947	July 20	49	0.1	25–35	30.1
	1948	June 11	33	0.01	10–15	13.0
	1948	June 14	96	0.02	10–16	13.2
	1948	June 19	42	0.03	11–21	15.6
	1948	June 25	41	0.05	20–28	23.2
	1948	June 29	17	0.1	24–33	26.5
Red Deer River, Alta.	1948	July 18–19	33	0.3	27–43	34.9
McKenzie Creek, Man.	1945	Aug. 15	130	2.6	52–82	67.4
	1946	Aug. 12	18	5.7	60–98	81.4
Baptizing Creek, Man.	1945	Aug. 14	235	2.2	51–73	62.5
	1946	July 26	20	2.2	47–69	59.9
	1946	Sep. 17–19	125	10.9	81–121	103.8
Saskatchewan R., Man.	1945	Aug. 23	105	3.9	46–94	72.4

Throughout its range the goldeye reaches several inches in length during the first few months after hatching. Harlan and Speaker (1951) record underyearlings in Iowa reaching 3.0 to 5.0 inches (76–127 mm) in length by fall and Trautmann (1957) states that specimens from Ohio waters reach 5.0 to 6.5 inches (127–165 mm) by October. A sample of 125 underyearlings taken from Baptizing Creek, Manitoba between September 17 and 19, 1946, averaged 4.1 inches (104 mm) in fork length. The first season's growth is slower in northern waters. A sample of 67 yearlings collected on June 3, 1948, at Lake Claire, Alberta, averaged 2.7 inches (69 mm) in fork length, and 8 yearlings collected on June 5, 1949, averaged 3.6 inches (91 mm). Although there is a marked annual difference in growth, yearling goldeye from Lake Claire are smaller than underyearlings taken in the fall in more southern waters.

REFERENCES

ANON. 1898. A manual of fish culture. *U.S. Commission of Fish and Fisheries, Appendix to the Commissioner's Report* for 1897, **23**: 1–340.

BATTLE, H. I. 1929. Effects of extreme temperatures and salinities on the development of *Enchelyopus cimbrius* (L.). *Contr. Canadian Biol. and Fish.*, N.S. **5**: 109–192.

BIGELOW, H. B., AND W. C. SCHROEDER. 1953. Fishes of the Gulf of Maine. *U.S. Fish and Wildlife Service, Fish. Bull.*, **53**: 1–577.

BRINLEY, F. J. 1938. Eggs of fishes. *Tabulae Biologicae*, **16**: 51–59.

DAVIS, C. C. 1959. A planktonic fish egg from fresh water. *Limnology and Oceanography*, **4**(3): 352–355.

EHRENBAUM, E. 1905, 1909. I. Eier und Larven von Fischen, andere Eier und Cysten. *Nordisches Plankton*, **1** 1905: 1–216; 1909: 217–414. Kiel and Leipzig.

FISH, M. P. 1932. Contributions to the early life histories of 62 species of fishes from Lake Erie and its tributary waters. *Bull. U.S. Bur. Fish.*, **47**: 293–298.

HARLAN, J. R., AND EVERETT B. SPEAKER. 1951. Iowa fish and fishing. State of Iowa, pp. 1–237.

HILDEBRAND, S. F., AND L. E. CABLE. 1930. Development and life history of fourteen teleostean fishes at Beaufort, N.C. *Bull. U.S. Bur. Fish.*, **46**: 383–488.

HORA, S. L., AND T. V. R. PILLAY. 1955. Handbook on fish culture in the Indo-Pacific region. Provisional edition (mimeographed); Food and Agricultural Organization of the United Nations, Rome, pp. i–ii, 1–264.

KUNTZ, A. 1916. Notes on the embryology and larval development of five species of teleostean fishes. *Bull. U.S. Bur. Fish.*, **39**: 409–429.

KYLE, M. 1926. The biology of fishes. MacMillan Co., New York, pp. 1–396.

LEACH, G. C. 1923. Artificial propagation of whitefish, grayling and lake trout. *Rep. U.S. Comm. of Fish.* for 1923, Appendix 3, pp. 1–32. [U.S. Bur. of Fish., Doc. No. 949.]

LEIM, A. H. 1924. The life history of the shad (*Alosa sapidissima* Wilson) with special reference to the factors limiting its abundance. *Contr. Canadian Biol.*, N.S. **2**(11): 163–284.

MANSUETI, R. 1958. Eggs, larvae and young of the striped bass, *Roccus saxatilis*. *Maryland Dept. Research and Education, Chesapeake Biol. Lab., Contr.* No. 112, pp. 1–35.

MCINTOSH, W. C., AND A. T. MASTERMAN. 1897. The life histories of the British marine food-fishes. London, C. J. Clay and Sons, pp. 1–516.

MERRIMAN, D. 1941. Studies on the striped bass (*Roccus saxatilis*) of the Atlantic Coast. *U.S. Fish and Wildlife Service, Fish. Bull.*, **50** (35): 1–77.

MOOKERJEE, H. K. 1945. Identification of eggs of common fishes of Bengal. *Science and Culture*, **11**(1): 48.

MOORE, G. A. 1944. Notes on the early life history of *Notropis girardi*. *Copeia* for 1944, pp. 209–214.

PEARSON, J. C. 1938. The life history of the striped bass, or rockfish, *Roccus saxatilis* (Walbaum). *Bull. U.S. Bur. Fish.*, **49**(28): 825–851.

PRICE, JOHN. 1924. Embryology of the whitefish, (*Coregonus clupeaformis* Mitchill). *Ohio. J. Sci.*, **34**: 287–305.

RAUTHER, M., AND M. LAINER. 1937. Dr. H. G. Bronn's Klassen and Ordnungen des Tierreichs. **6**(1): (2): Echte Fische (5): 772.

REIGHARD, J. 1890. The development of the wall-eyed pike (*Stizostedion vitreum*, Raf.). *9th Bienn. Rept. Michigan State Board Fish. Comm., App.*, pp. 95–158.

STENGER, J. 1956. Key to the eggs of the known species of fishes of Passamaquoddy Bay, New Brunswick. *Ontario Field Biologist*, **10**: 22–25. Toronto.

TRACY, H. C. 1920. The membranous labyrinth and its relation to the precoelomic diverticulum of the swim bladder in clupeoids. *J. Comp. Neurol.*, **31**: 219–258.

TRAUTMANN, MILTON B. 1957. The fishes of Ohio. Ohio State University Press, pp. 1–683.

WEBSTER, D. A. 1942. The life histories of some Connecticut fishes. Section III in A fishery survey of important Connecticut lakes. *Connecticut Geol. and Nat. Hist. Surv. Bull.*, **63**: 122–227.

WILSON, H. V. 1891. The embryology of the sea bass (*Serranus atrarius*). *Bull. U.S. Fish. Comm.* for 1889, **9**: 209–277.

Description of Young Ammocoetes belonging to Two Species of Lampreys: *Petromyzon marinus* and *Entosphenus lamottenii*[1]

By Vadim D. Vladykov

Department of Biology, University of Ottawa, Ottawa, Ont.

ABSTRACT

The description of young ammocoetes, 19–68 mm in length, belonging to *Petromyzon marinus* and *Entosphenus lamottenii*, is given. The principal differences between species consist in the intensity and pattern of the pigmentation. For identification, in decreasing order of importance, the different sections of an ammocoete are as follows: the dorsal surface of the head and trunk, the lateral side of the head, and the tail region. Among the other characters are described the peritoneum, which is pale, unpigmented in *E. lamottenii* and darkly pigmented in *P. marinus*; and the precursor of the tongue, the dark pigmentation of which is found in 98% of *E. lamottenii* and only in 11% of *P. marinus*.

Ten years ago the author (Vladykov, 1950) described characters by means of which ammocoetes of three eastern American lampreys with two separate dorsal fins can be identified. These characters were based principally on the intensity and pattern of pigmentation, their degree of development being directly related to the size (or age) of an ammocoete. As it was the first paper which ventured to identify accurately the larval lampreys of different species, a subject previously considered impossible, the description of larger ammocoetes only, from 60 mm up, was given.

The correctness of the above-mentioned characters was abundantly verified by numerous investigators in Canada and the United States, especially by those working under the Great Lakes Fishery Commission. Hundreds of different streams were examined to determine the kinds of ammocoetes they harboured.

[1]Received for publication January 28, 1960.

J. Fish. Res. Bd. Canada, 17(2), 1960.
Printed in Canada.

In spite of this, some authors, for instance Trautman (1957, p. 74) in his paper on Ohio fishes, claim that identification of ammocoetes using morphological characters alone is impossible. However, Bailey (1959, p. 181), in reviewing this publication, criticizes strongly the erroneous statement by Trautman. Moreover, Hubbs and Lagler (1959, p. 35), in their recent revision of "Fishes of the Great Lakes", used characters from Vladykov (1950) for identification of larval lampreys with two dorsal fins.

The present paper, which is a complement to the 1950 paper on the same subject, contains a description of young ammocoetes from 19 to 68 mm in length, belonging to the sea lamprey *Petromyzon marinus* Linnaeus, and the American brook lamprey *Entosphenus lamottenii* (Le Sueur).

MATERIAL

The present study was based on extensive material of *P. marinus* and *E. lamottenii* ammocoetes obtained from different localities in eastern North America and Europe (France and Portugal). The collections contain ammocoetes of a wide range in size, from those taken from nests, in the case of *P. marinus* of about 10 mm, to those in different stages of transformation. The material was preserved in 4 to 5% formalin.

In the present paper, for a more detailed comparison, ammocoetes of similar sizes were selected. Preference was given to those collected with an electric shocker, as they are better preserved than specimens which were poisoned with lampricide. The accompanying photographs of ammocoetes with two dorsal fins were made from specimens collected in the Lakes Huron and Superior drainage. The sea lamprey larvae were obtained both from the North Channel (Watson's Creek) and from Georgian Bay (Silver and Lamont Creeks). The American brook lamprey were obtained from Watson's Creek, and Sable River, Lake Superior. A specimen of *Ichthyomyzon fossor* (identification provisional) from the Batchawana River, Lake Superior, was also photographed for comparison.

The size of the ammocoetes mentioned in the text refers to the total length and is that of an animal measured after being preserved in formalin. The length of a live ammocoete is somewhat (2 to 3%) greater than that of a preserved one.

The photographed ammocoetes were collected by Dr J. J. Tibbles and his assistants using an electric shocker. In legends under the plates illustrating this paper, in addition to collection data, the size of the ammocoete and its catalogue number are given. In each of the plates, except Plate 13, the ammocoetes were represented by three views: the upper photograph shows the dorsal view of the head and trunk, the middle one shows the lateral view of the head region, and the lower one shows the lateral view of the tail region.

CHARACTERS USEFUL FOR IDENTIFICATION

As in the case of larger ammocoetes (Vladykov, 1950), the pattern and density of dark pigmentation are the most important characters for identification of ammocoetes belonging to different species. In their order of importance, the individual sections of an ammocoete are as follows.

Dorsal Surface of Head and Trunk

In ammocoetes less than 60 mm long, the pattern of pigmentation over the dorsal surface of the head and trunk is of prime significance and is illustrated in the upper photographs of the plates. There are four important points to be considered.

1. *Post-nostril area:* The size of this non-pigmented area is different in both our species. In *P. marinus* it is typically smaller than the nostril itself, while in *E. lamottenii* this unpigmented area is about twice the size of the nostril.

2. *Cephalic dark line:* It is found in the middle of the posterior section of the head. It is very dark, nearly black in colour, situated in the cartilaginous brain capsule and is easily seen through the transparent skin when examined under a low-power microscope. In *E. lamottenii*, which in general is less pigmented, this dark line stands out very clearly in ammocoetes from 19 to 60 mm in length. In young ammocoetes of *P. marinus* up to about 30 mm, this line is also pronounced, but in larger specimens it is almost indistinguishable due to strong development of pigment in the skin.

3. *Cephalic oblique muscular septa:* These septa, which represent the dorsal extensions of myomeres, are seen on either side of the cephalic dark line. Their anterior ends are directed closer together than the posterior ends. In ammocoetes of *P. marinus* the chromatophores are situated quite regularly along the septa, making them quite pronounced. Conversely, in ammocoetes of *E. lamottenii* the pigment cells are less abundant but larger in size, and placed irregularly, thus masking almost completely the oblique septa.

4. *Mid-dorsal band:* The width of non-pigmented areas over the dorsal surface of the trunk is compared to a distance measured horizontally between the first and second branchial or gill-openings. The distance is referred to as B_1–B_2. To make the comparison more accurate, the width of the non-pigmented dorsal area was always measured at the level of the 5th gill-opening.

The width of the mid-dorsal band varies with the species and size of the ammocoete. The dark colour of the notochord can be seen through the middle of the mid-dorsal band in larvae of both species shorter than 40 mm. As the skin grows thicker in larger ammocoetes, this dark line becomes unnoticeable from the outside. In the case of *P. marinus*, even in very young larvae (19 to 24 mm),

the width of the dorsal band is a little narrower than the B_1–B_2 distance; in older ammocoetes it becomes even narrower. In very small larvae (19 to 24 mm) of *E. lamottenii*, there are practically no chromatophores found over the dorsal surface, thus the dorsal band corresponds to the width of the back, being about twice as wide as the B_1–B_2 distance. In ammocoetes between 40 and 50 mm, this band is still a little wider than the B_1–B_2 distance, and only in large larvae do these two become equal.

Lateral Side of the Head

In the earlier publication (Vladykov, 1950, p. 80), the principal pigmented areas found on the lateral side of the head were described and figured. In the case of young ammocoetes, the following three areas are of importance, and these are illustrated in the middle photographs of the plates in this paper.

1. *Upper lip:* In *P. marinus*, ammocoetes of all sizes have chromatophores more abundantly developed and found quite close to the lower edge of the lip. On the other hand, in ammocoetes of *E. lamottenii*, usually more than the lower half of the lip remains unpigmented.

2. *Prebranchial blotch:* In ammocoetes of *P. marinus* of all sizes, this area, extending from the rear of the upper lip to the first gill-opening, is well pigmented, while in *E. lamottenii* larvae it remains white and unpigmented.

3. *Branchial region:* In both large and small ammocoetes of *P. marinus*, the chromatophores descend from the back nearly to the upper margins of the gill-openings. In *E. lamottenii* larvae, there is a very wide unpigmented band above the gill-openings.

Tail Region

As already pointed out for large ammocoetes (Vladykov, 1950, p. 80), there are two important areas which can help to identify lamprey larvae of different species. The lower photographs in the plates of the present paper illustrate these areas.

1. *Caudal peduncle:* In *P. marinus* ammocoetes of any size down to 19 mm, there are well-developed chromatophores descending to the lower edge of the peduncle. In all *E. lamottenii* larvae, regardless of their size, a white unpigmented band always remains along the lower edge.

2. *Caudal fin:* In large *P. marinus* ammocoetes the pigmentation of the caudal fin is well marked, and extends from the notochord to the extremity of the caudal rays, thus repeating the outline of the caudal margin and appearing *beaver-tail-like* (Vladykov, 1950, p. 83). In younger ammocoetes of *P. marinus* the "beaver-tail" is not developed as yet, but chromatophores are in abundance

and are located symmetrically along the dorsal and ventral edges of the notochord, extending to its posterior end. In ammocoetes of *E. lamottenii* up to 50 mm long, the posterior end of the notochord is not surrounded by chromatophores. Generally, in this species the caudal fin is poorly pigmented as illustrated in the plates.

Peritoneum

By cutting open the body cavity with the blade of a safety razor, the colour of the peritoneum of the ammocoete may be seen. This can be easily done[2] even in small larvae down to 40 mm.

Precursor of the Tongue

The description of this organ and the method of its dissection were given in a previous paper (Vladykov, 1950, pp. 90–92). It was found that it is helpful to separate different species of lampreys. In *P. marinus* ammocoetes it typically remains white, unpigmented, while the opposite is true for *E. lamottenii*. Table I, based principally on material from Quebec waters, contains supplementary

Table I. Difference in pigmentation of the precursor of the tongue in two species of lampreys.

Species	Total length	Proportion of ammocoetes with indicated degree of development of pigmentation			Number of specimens examined
		Complete	Partial	Absence	
	mm	%	%	%	
E. lamottenii	41–183	91.8	6.4	1.8	282
P. marinus	44–176	7.3	3.6	89.1	313

data on the pigmentation of the precursor of the tongue in ammocoetes of the two species.

Although this character is important in itself, unfortunately it is rather difficult to dissect the precursor of the tongue in ammocoetes smaller than 30 to 40 mm.

SUPPLEMENTARY INFORMATION

Colour Variations

The enclosed photographs and preceding text referred to typical ammocoetes of both species. However, in certain Great Lakes streams there are ammocoetes which are either more darkly pigmented than usual or very light in colour. There is a record of a true albino adult *P. marinus*, which was dug as a larva by Wilson (1954) from the sand at the mouth of Salmon River on Lake Champlain, New York.

[2]The dissection of ammocoetes smaller than 40 mm is rather difficult, and if incorrectly done may induce error in determining the colour of the peritoneum.

The "light colour" phase of *P. marinus* ammocoetes is especially important, as it makes them more difficult to distinguish from those of *E. lamottenii*. Thomas (personal communication, 1959) mentioned similar light-coloured sea lamprey ammocoetes from Youngs Creek which drains into Long Point Bay, Lake Erie. Plate 11 in the present paper illustrates one such specimen of *P. marinus* ammocoete from Silver Creek, Georgian Bay. In spite of its paleness, it retains all essential characteristics of *P. marinus*.

Fin Rays

In the literature there is occasionally found a misconception about the presence of rays in ammocoetes. For instance, Bigelow and Schroeder (1948, p. 45) in describing ammocoetes of *P. marinus* stated that their "fins are without rays". The specimens in the present author's collection show that rays begin to develop in the caudal and second dorsal fins in ammocoetes about 40 mm long in both *P. marinus* and *E. lamottenii*. In ammocoetes 50 to 55 mm long, the rays appear in the first dorsal fin as well. In ammocoetes from 60 mm up, rays are well developed in all fins (Plates 9–11).

Eyes

There is also the erroneous belief that the eyes in ammocoetes appear only during transformation. Speaking of ammocoetes of *P. marinus*, Bigelow and Schroeder (loc. cit., p. 45) stated that "eyes rudimentary and not visible externally". As the photographs (Plates 1–4) clearly show, in young ammocoetes of both *P. marinus* and *E. lamottenii* 19 to 30 mm long, eyes are visible externally through the thin, transparent skin. As the ammocoete grows older, its skin becomes thicker and hides the eye from the exterior. The eyes reappear again as functional organs in transforming specimens.

Ichthyomyzon Ammocoetes

Although the present paper deals only with lampreys with two dorsal fins, it is of importance to compare them with *Ichthyomyzon* ammocoetes possessing a single dorsal fin.

The most important characteristic of *Ichthyomyzon* species, that is, a single dorsal fin, is useful to separate them from other ammocoetes only when the latter are at least 40 mm long. In younger ammocoetes of any species the two dorsal fins are joined by a skin fold, thus giving the appearance of a single dorsal fin similar to that of *Ichthyomyzon*. As soon as the rays start to appear in the dorsal fins, the separation of individual species becomes easy.

Since every species of the genus *Ichthyomyzon* has less than 60 trunk myomeres[3] (Hubbs and Trautman, 1937; Vladykov, 1949, 1953), while our two species

[3]Trautman (1957, pp. 137–142) gives higher myomere counts for Ohio lampreys: 53 to 62 for *I. greeleyi* and *bdellium*, and 63 to 80 for *P. marinus*.

with two separate dorsal fins possess between 63 and 74 myomeres, ammocoetes of either group are easily separable by this character. Since in *Ichthyomyzon* ammocoetes the myomeres are rather wide, especially over the caudal region, this character permits easy separation of them from other lamprey species (Plate 12), even without counting the trunk myomeres. Moreover, the bodies of *Ichthyomyzon* larvae are laterally compressed while those of other species are rounded.

As the intention of the present author is to publish in the near future a comprehensive key to separate different ammocoetes of the genus *Ichthyomyzon*, only a brief remark will be given here. The revision of the genus *Ichthyomyzon* by Hubbs and Trautman (1937) pointed out clearly that the six known species[4] are naturally grouped in pairs, one member of which is parasitic and the other non-parasitic.

In addition to differences in the number of trunk myomeres and particular patterns of pigmentation, the ammocoetes of different pairs, at least the large ones from 60 mm up, can be separated by peculiarities of pigmentation of their lateral line organs. It was already pointed out by the author (Vladykov, 1953) at the 33rd annual meeting of the American Society of Ichthyologists and Herpetologists, that only the ammocoetes of the pair *unicuspis–fossor* are characterized by whitish, non-pigmented lateral line organs, while those of the two remaining pairs *castaneus–gagei* and *bdellium–greeleyi* have darkly pigmented organs of the lateral line.

ACKNOWLEDGMENTS

Much of this work was done during the writer's seasonal employment by the Fisheries Research Board of Canada. Dr W. A. Kennedy, Director of the Board's Biological Station, London, Ont., encouraged this investigation, and members of his staff, particularly Dr J. J. Tibbles and Mr M. L. H. Thomas, provided the valuable material. Mr G. A. Ben-Tchavtchavadze of the University of Ottawa expertly took the photographs of ammocoetes. To all these persons, the author wishes to express his most sincere thanks.

[4] *Ichthyomyzon hubbsi*, described recently by Raney (1952), is considered here as synonymous with *I. greeleyi*.

REFERENCES

BAILEY, R. M. 1959. Review of "The fishes of Ohio with illustrated keys", by M. B. Trautman. *Copeia*, **1959**(2): 179–181.

BIGELOW, H. B., AND W. C. SCHROEDER. 1948. Cyclostomes. *In* Fishes of the Western North Atlantic. *Memoir of Sears Foundation for Marine Research*, No. 1, Part 1: 29–58.

HUBBS, C. L., AND K. L. LAGLER. 1958. Fishes of the Great Lakes region. *Bull. Cranbook Inst. Sci.*, No. 26: xi + 1–213.

HUBBS, C. L., AND M. B. TRAUTMAN. 1937. A revision of the lamprey genus *Ichthyomyzon*. *Misc. Publ. Mus. Zool. Univ. Michigan*, No. 35: 1–109.

RANEY, E. C. 1952. A new lamprey, *Ichthyomyzon hubbsi*, from the upper Tennessee River system. *Copeia*, **1952**(2): 91–99.

TRAUTMAN, M. B. 1957. The fishes of Ohio with illustrated keys. xviii+1–683. The Ohio State University Press.

VLADYKOV, V. D. 1949. Quebec lampreys (Petromyzonidae). I. List of species and their economical importance. *Dept. of Fish. Quebec, Contrib.* No. 26: 1–67.

1950. Larvae of eastern American lampreys (Petromyzonidae). I. Species with two dorsal fins. *Nat. Canadien*, **77**(3–4): 73–94.

MS. 1953. Tentative taxonomy of ammocoetes of genus *Ichthyomyzon*. Ottawa, Ont. 9 pp.

WILSON, F. H. 1954. The lake lamprey—menace to Great Lakes fishing. Lebanon Valley College (Annville, Pa.). *LVC Alumni News*, January, 1954: 6–7.

PLATES I–XIII

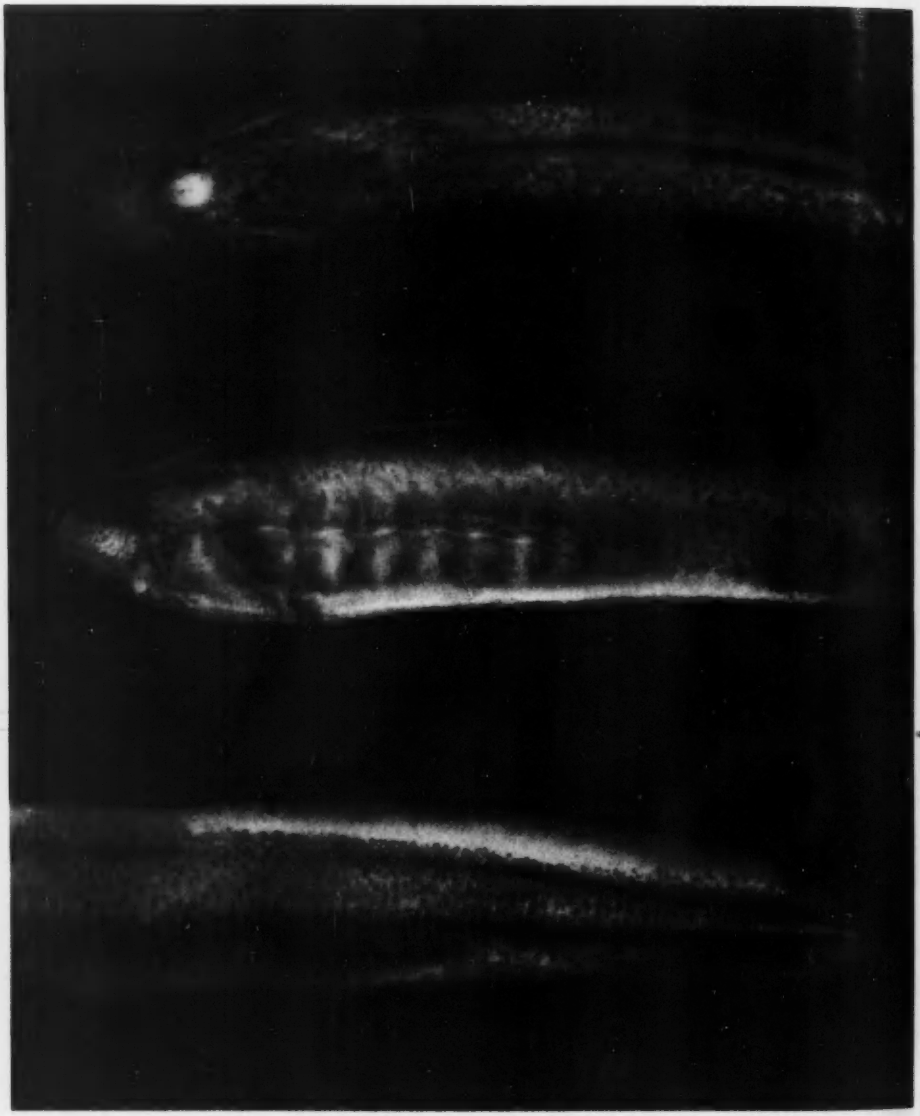

PLATE 1. *P. marinus* ammocoete (No 3812-R), 19 mm long, taken on October 5, 1957, in Watson's Creek, North Channel, Ont.

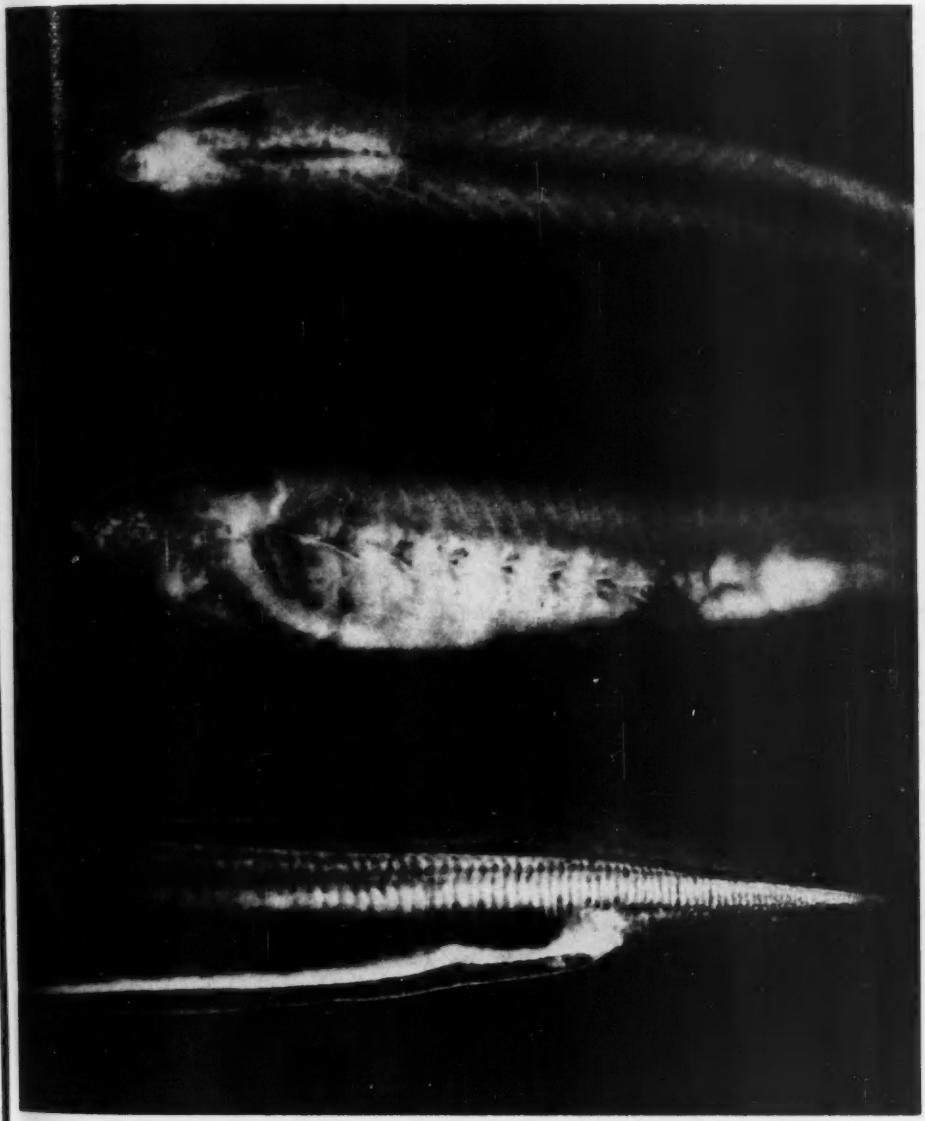

PLATE 2. *E. lamottenii* ammocoete (No 2793-J), 19 mm long, taken on October 5, 1957, in Watson's Creek, North Channel, Ont.

PLATE 3. *P. marinus* ammocoete (No 3813-R), 24 mm long, taken on May 23, 1956, in Lamont Creek, Georgian Bay, Ont.

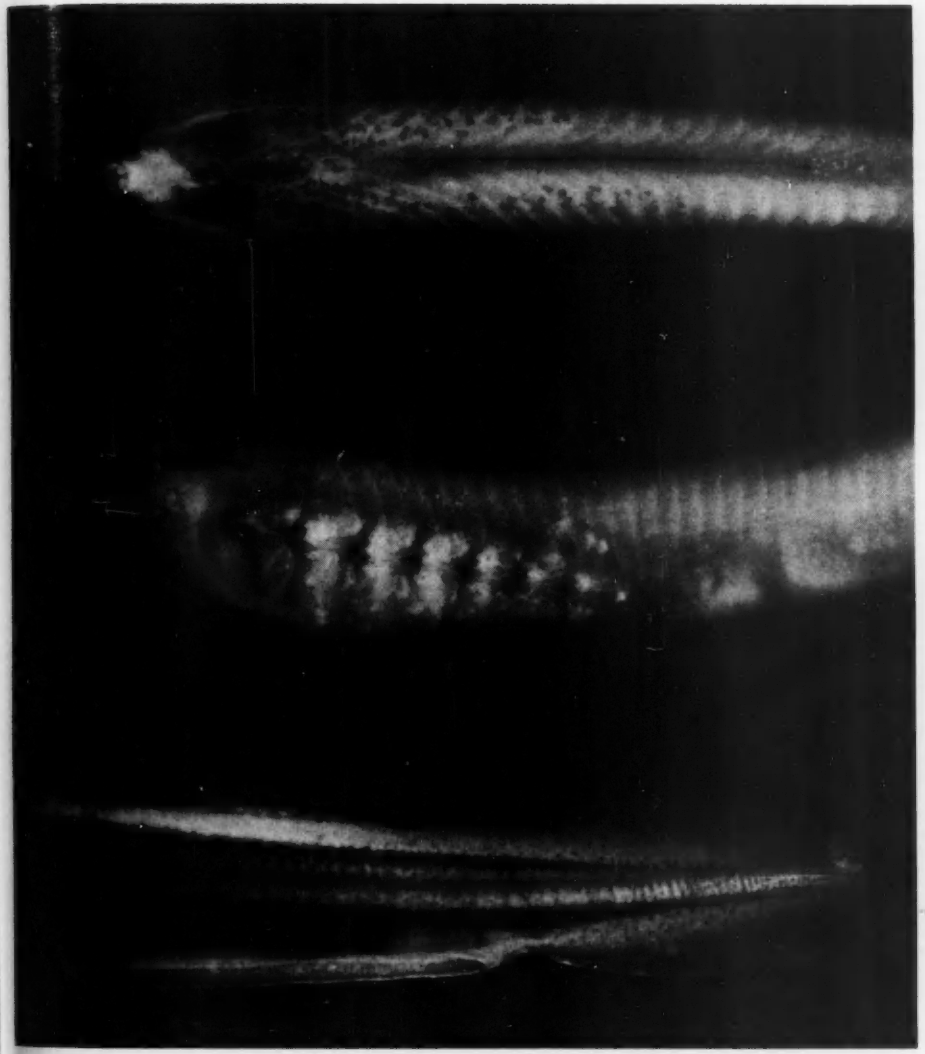

PLATE 4. *E. lamottenii* ammocoete (No 2794-J), 24 mm long, taken on October 5, 1957, in Watson's Creek, North Channel, Ont.

PLATE 5. *P. marinus* ammocoete (No 3814-R), 29 mm long, taken on May 23, 1956, in Lamont Creek, Georgian Bay, Ont.

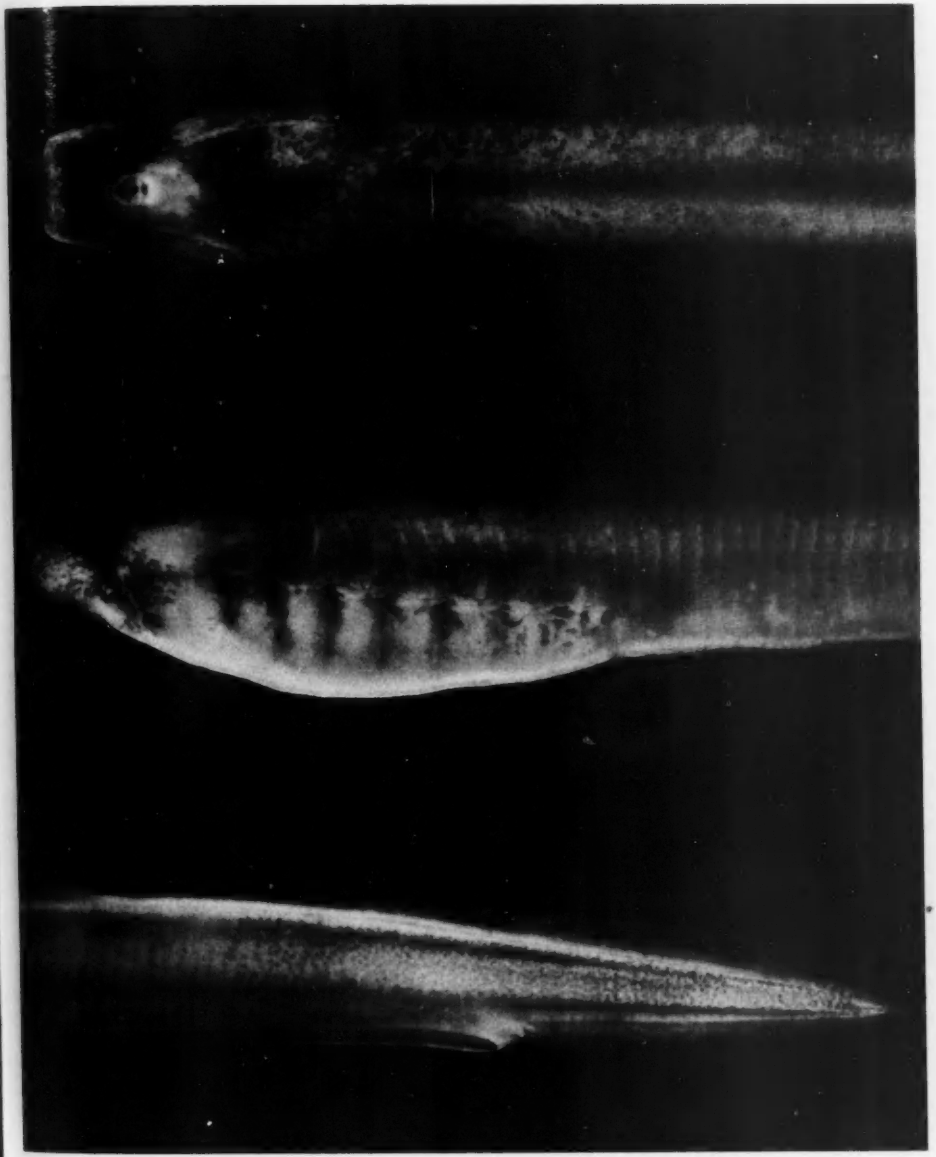

PLATE 6. *E. lamottenii* ammocoete (No 2796-J), 38 mm long, taken on October 5, 1957, in Watson's Creek, North Channel, Ont.

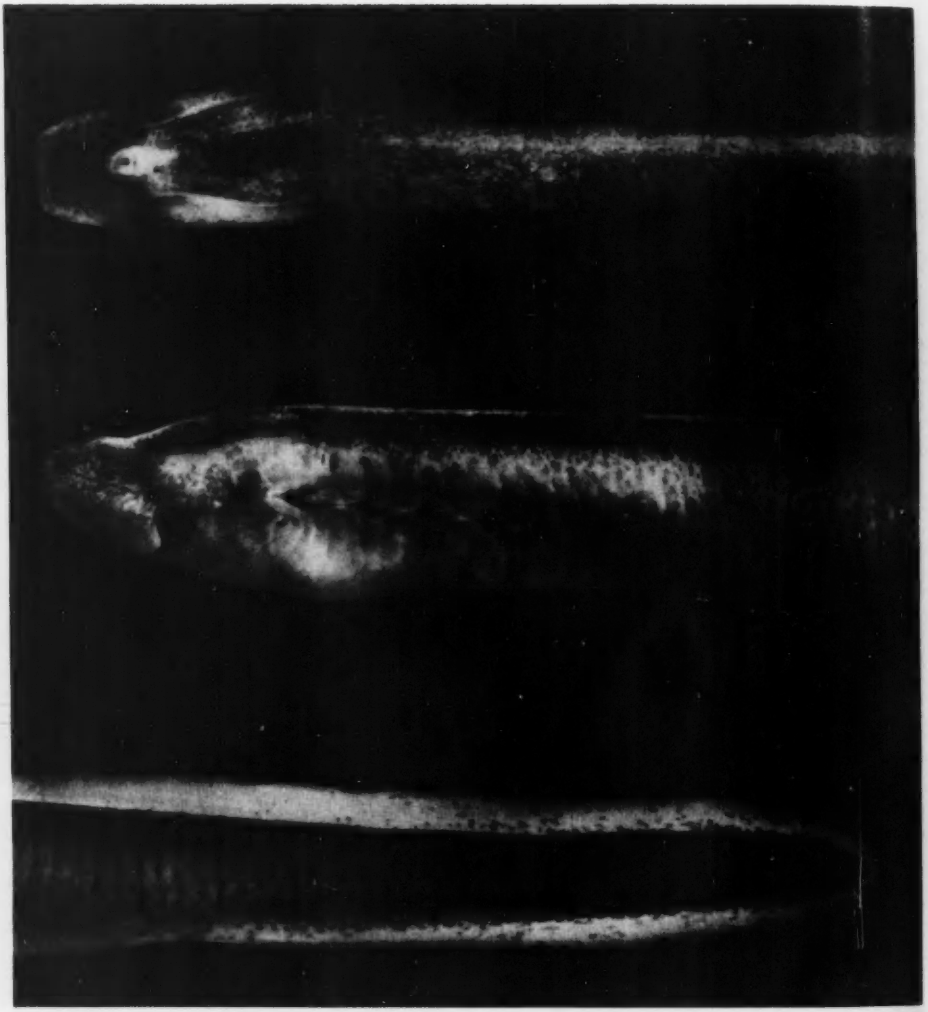

PLATE 7. *P. marinus* ammocoete (No 3816-R), 44 mm long, taken on April 10, 1957, in Silver Creek, Georgian Bay, Ont.

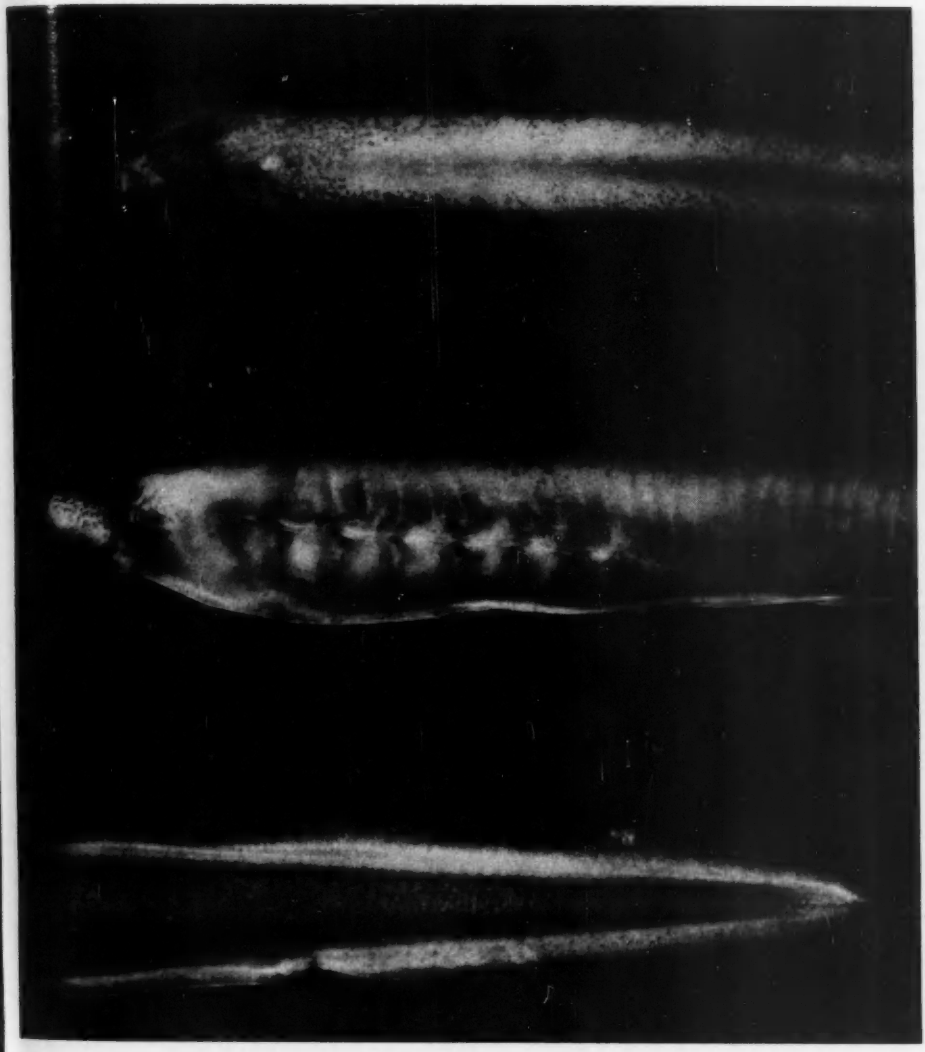

PLATE 8. *E. lamottenii* ammocoete (No 2797-J), 47 mm long, taken on October 5, 1957, in Watson's Creek, North Channel, Ont.

PLATE 9. *P. marinus* ammocoete (No 3817-R), 59 mm long, taken on April 10, 1957, in Silver Creek, North Channel, Ont.

PLATE 10. *E. lamottenii* ammocoete (No 2798-J), 68 mm long, taken on July 17, 1959, in Sable River, Lake Superior, Ont.

PLATE 11. *P. marinus* ammocoete (No 3819-R), 63 mm long, taken on April 10, 1957, in Silver Creek, North Channel, Ont.

PLATE 12. *I. fossor* ammocoete (No 3364-V), 49 mm long, taken on July 19, 1959, in Batchawana River, Lake Superior, Ont.

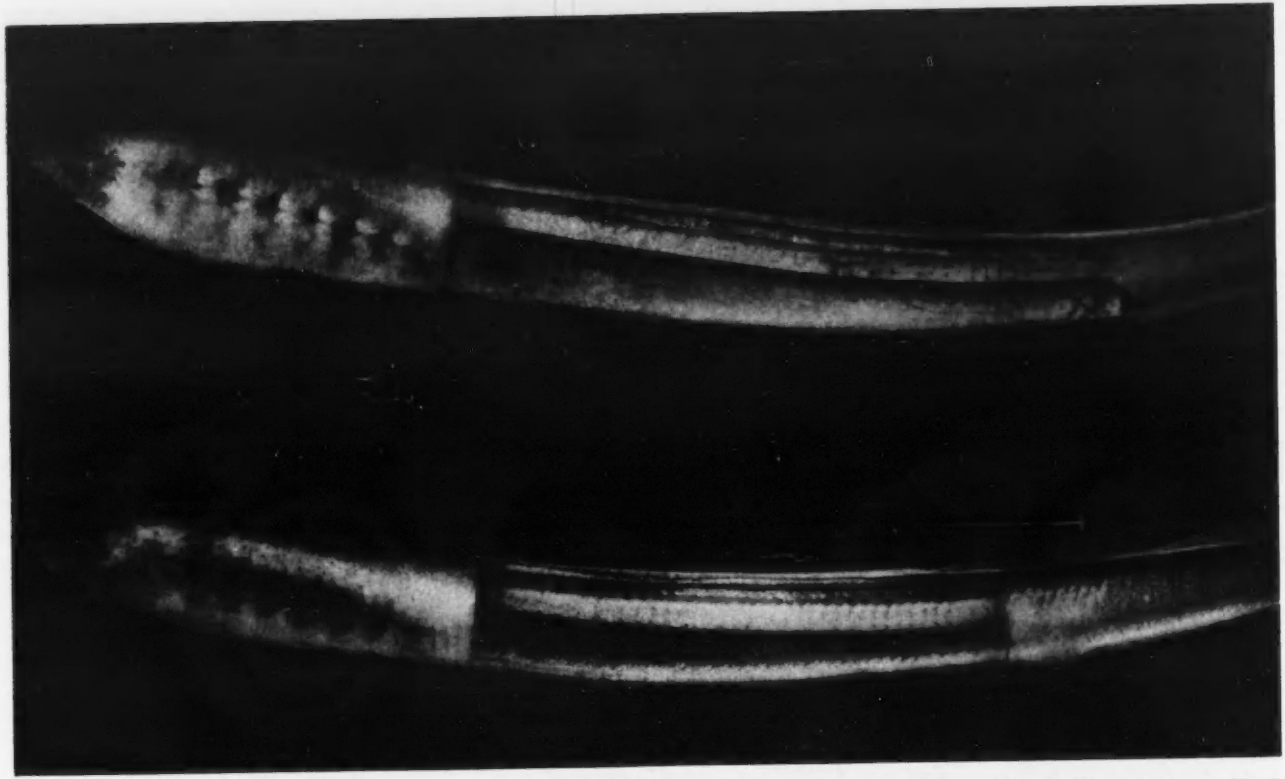

PLATE 13. Upper photograph: *E. lamottenii* ammocoete (No 1151–Y), 50 mm long, taken on October 5, 1957, in Watson's Creek, North Channel, Ont.
Note pale, unpigmented peritoneum.
Lower photograph: *P. marinus* ammocoete (No 3815–R), 49 mm long, taken on April 10, 1957, in Silver Creek, North Channel, Ont.
Note dark, densely pigmented peritoneum.

Note dark, densely pigmented peritoneum.

Note on *Pontonema vacillatum* Leidy 1855 (Nematoda: Oncholaimidae) from Soft-shell Clams (*Mya arenaria*)

Oncholaimid nematodes have been found along the mantle and in the folds of the neck skin of a large percentage of soft-shell clams (*Mya arenaria*) from the lower beach zone at Harbour de Loutre, Seal Rock Area, Campobello Island in the Bay of Fundy, collected by Mr R. M. Bond, Canada Department of Fisheries, St. Andrews, N.B. Some specimens were found partially imbedded in the epidermis of the neck. Study showed these specimens belonged to *Pontonema* Leidy 1855, a genus embracing free-living marine species. Accordingly, examination of the mud about clams at Campobello Island revealed these nematodes in some numbers. Morphological studies showed they were exceedingly close in most respects to descriptions of the generotype *vacillatum* Leidy 1855 originally collected off the coast of Maine, U.S.A. The types were redescribed by Walton (1927) and later in much more detail by Cobb and Steiner (1934). Our material agrees well with the few details given by Walton but the spicules and gubernaculum do not agree with the description of these structures given by Cobb and Steiner. These latter authors described the gubernaculum as "of complicated structure and almost as long as the spicules themselves". Their figure indicated that the spicules were distally alate and notched. In addition, they described the eggs as 45 × 55μ in size, much smaller than those in our material. Apart from these features, our specimens agree strikingly with the description of Cobb and Steiner. Accordingly the type specimens of *vacillatum* were obtained through the courtesy of Dr Frederick A. Aldrich, Associate Curator of Limnology of the Academy of Natural Sciences of Philadelphia, to whom we are much indebted. Study of these types showed clearly that Cobb and Steiner's description of the egg, spicules and gubernaculum is erroneous and that the nematodes collected from Campobello Island belong to *vacillatum*. Apart from the errors noted above, the description of Cobb and Steiner is accurate. We give below a brief description of a male and female specimen from our collection.

Pontonema vacillatum Leidy 1855

(Figs. 1–3)

MALE: L., 14.0 mm.; a = 68; b = 12; c = 127; gubernaculum, 64μ. Spicules, 140μ. Head width, 61μ. Nerve ring, 440μ. Stoma, 86 × 41μ. Width at anus, 112μ.

FEMALE: L., 13.3 mm.; a = 59; b = 11; c = 102; V = 51%; G1 = 20%; G2 = 25%. Head width, 62μ. Nerve ring, 460μ. Stoma,

86 × 43μ. Width at anus, 103μ. Eggs, 235 × 117μ, unsegmented, shell smooth, moderately thick.

SPECIMENS: United States National Museum, No. 56009.

HABITAT: Along the edge of the mantle of *Mya arenaria* from the lower beach zone at Harbour de Loutre, Campobello Island, Bay of Fundy, Canada.

REMARKS: We presume that *P. vacillatum* enter feeding clams and are able to live within the mantle; specimens survived for several days in mantle fluid. Further study may determine if they can feed and reproduce in the mantle cavity.

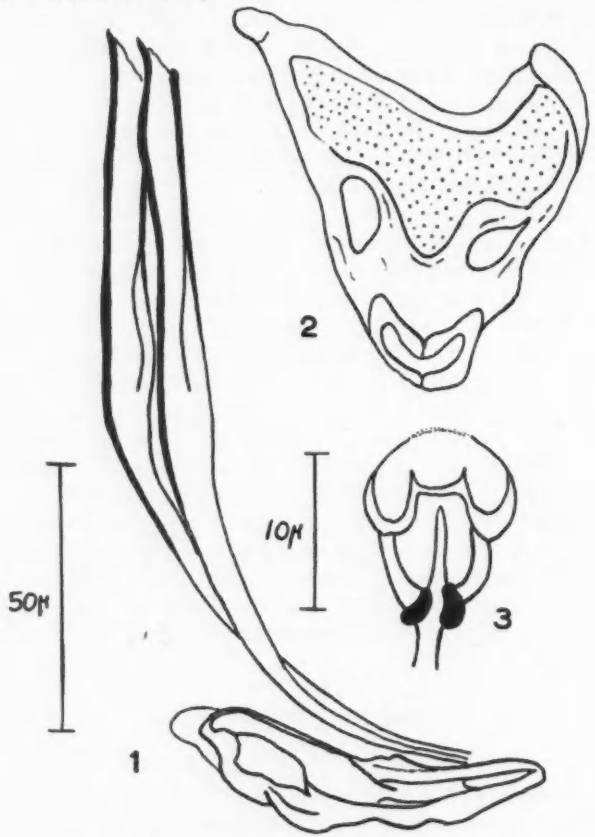

FIG. 1. Spicules and gubernaculum, lateral view.

FIG. 2. Gubernaculum, ventral view, flattened under coverslip; same scale as preceding.

FIG. 3. Amphid, lateral view.

REFERENCES

COBB, N. A., AND G. STEINER. 1934. An annotation on the nematode genus *Pontonema* Leidy, 1855. *J. Washington Acad. Sci.*, **24**: 56–59.

WALTON, A. C. 1928. A revision of the nematodes of the Leidy collection. *Proc. Acad. Nat. Sci. Philadelphia*, **79**: 49–163.

Department of Parasitology, ROY C. ANDERSON
Ontario Research Foundation, Toronto 5, Ont.

Fisheries Research Board of Canada, NEIL BOURNE
Biological Station, St. Andrews, N.B.

Received for publication December 29, 1959.